HUNT FOR DARK MATTER & DARK ENERGY

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# ALL ABOUT SPACE™

ISSUE 149
NOVEMBER 2023

SPECIAL REPORT

## EARTH IN DANGER

HAVE OUR LIFE-SUPPORT SYSTEMS BEEN DAMAGED BEYOND REPAIR?

HUBBLE VS WEBB

## EXPANSION OF THE UNIVERSE

WHAT CONTRADICTORY OBSERVATIONS FROM NASA'S SPACE TELESCOPES REVEAL ABOUT THE FATE OF SPACE AND TIME

## "HOW I BECAME AN ASTRONAUT"

SPACE SHUTTLE MISSION VETERAN JAN DAVIS

+

HEROES OF SPACE: NASA'S JESSICA WATKINS

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# WELCOME

ISSUE 149

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Christmas is almost upon us, with many of us in the midst of buying gifts. I occasionally open my inbox to find readers asking for advice on the best telescope to buy, with a list of things you – or the recipient – are looking to observe, the budget and whether the observer is a beginner or more seasoned astronomer. This month, you'll find the usual advice on what to observe, the kit you should be buying and honest reviews on the latest piece of equipment. But next issue – which marks our massive 150th – I'll be compiling all of your queries to make sure that you're never short of advice on choosing the very best kit, whatever your level of observing experience.

Back to this issue, one of the last of 2023, we hope you enjoy what else we have in store for you: we look into another mystery of the universe, answer some mind-boggling questions with our experts, uncover a special report on a first-of-its-kind health check on Earth, give insight into new observations made of the universe by the James Webb Space Telescope and so much more. Enjoy the issue, and see you next time!

**GEMMA LAVENDER**
Editor

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ON SALE 30 NOVEMBER

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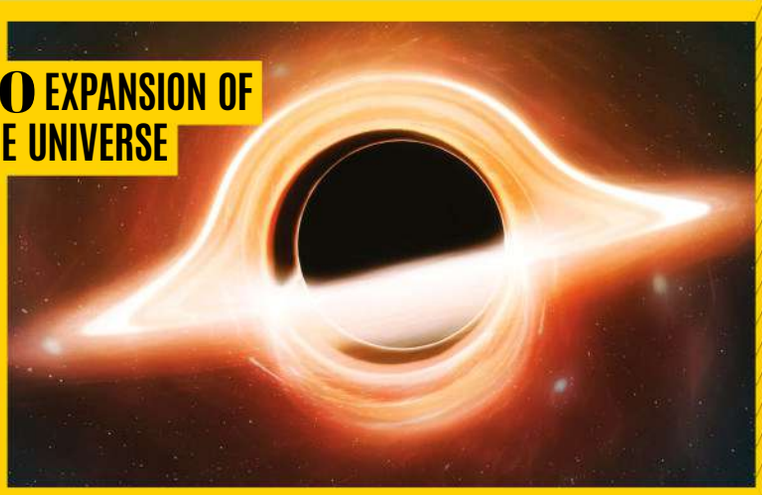


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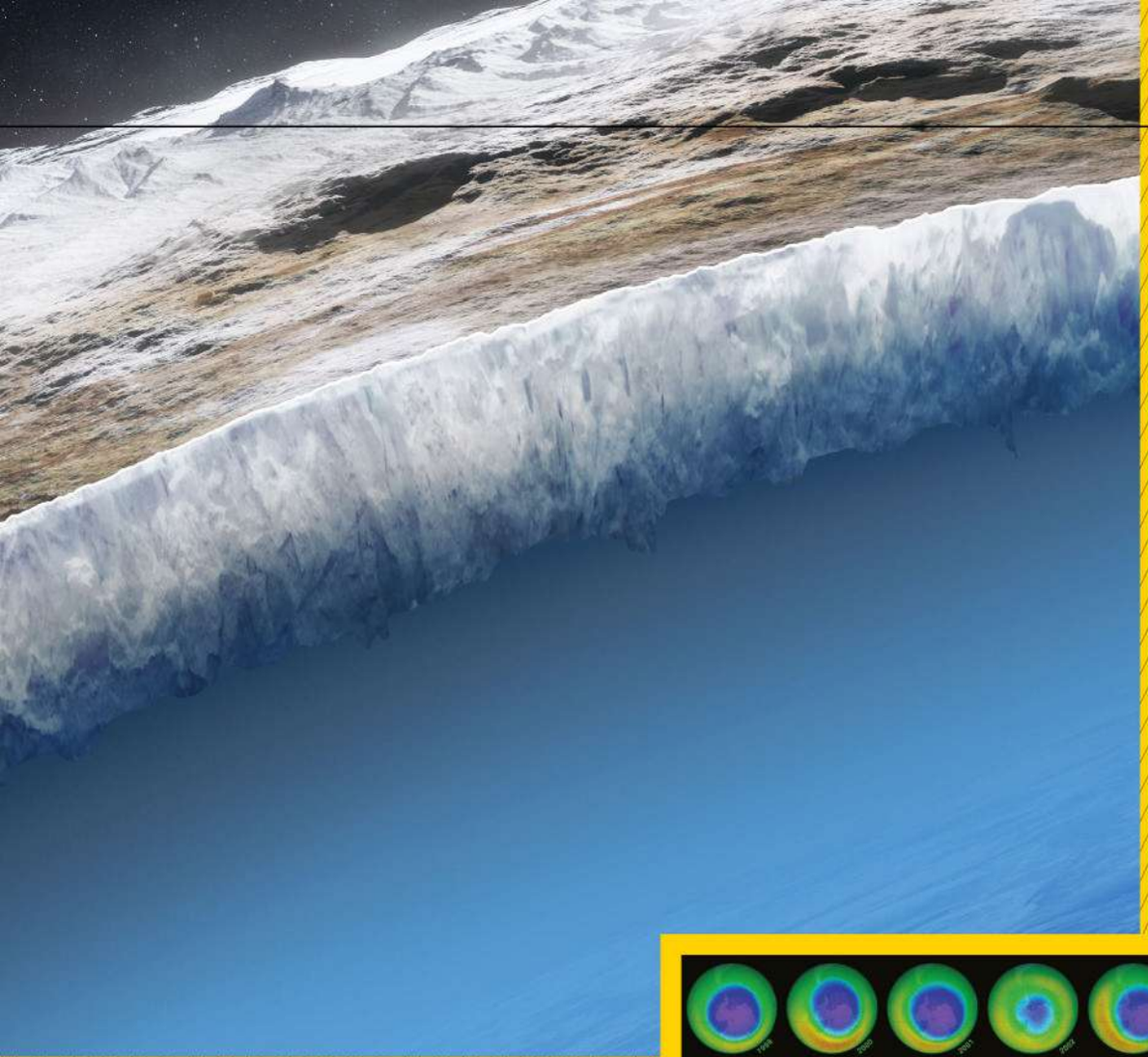

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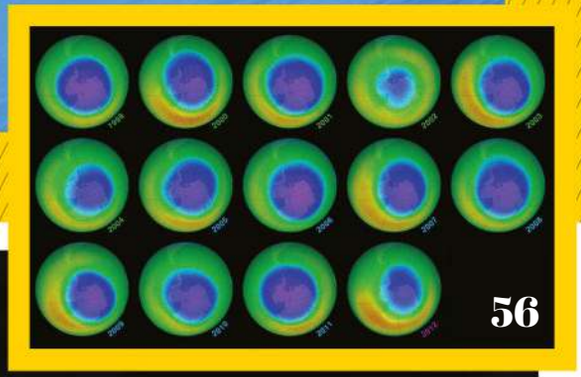


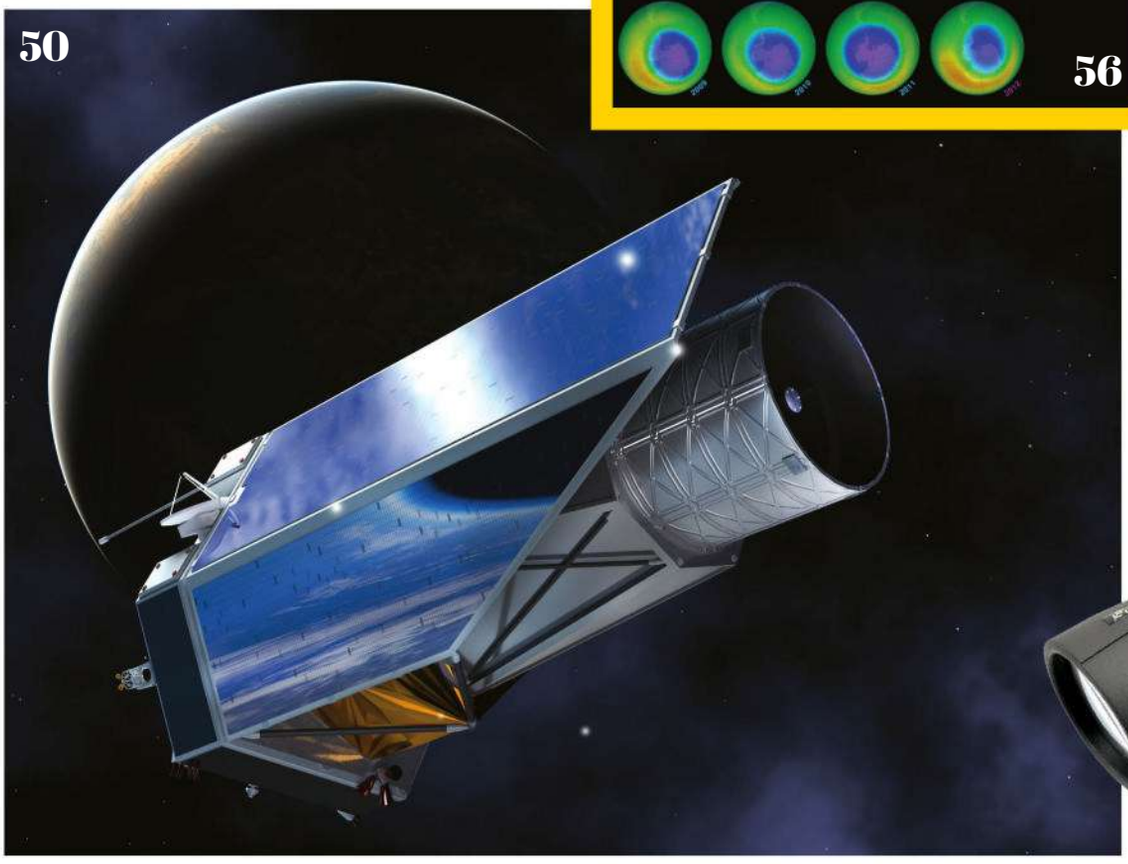


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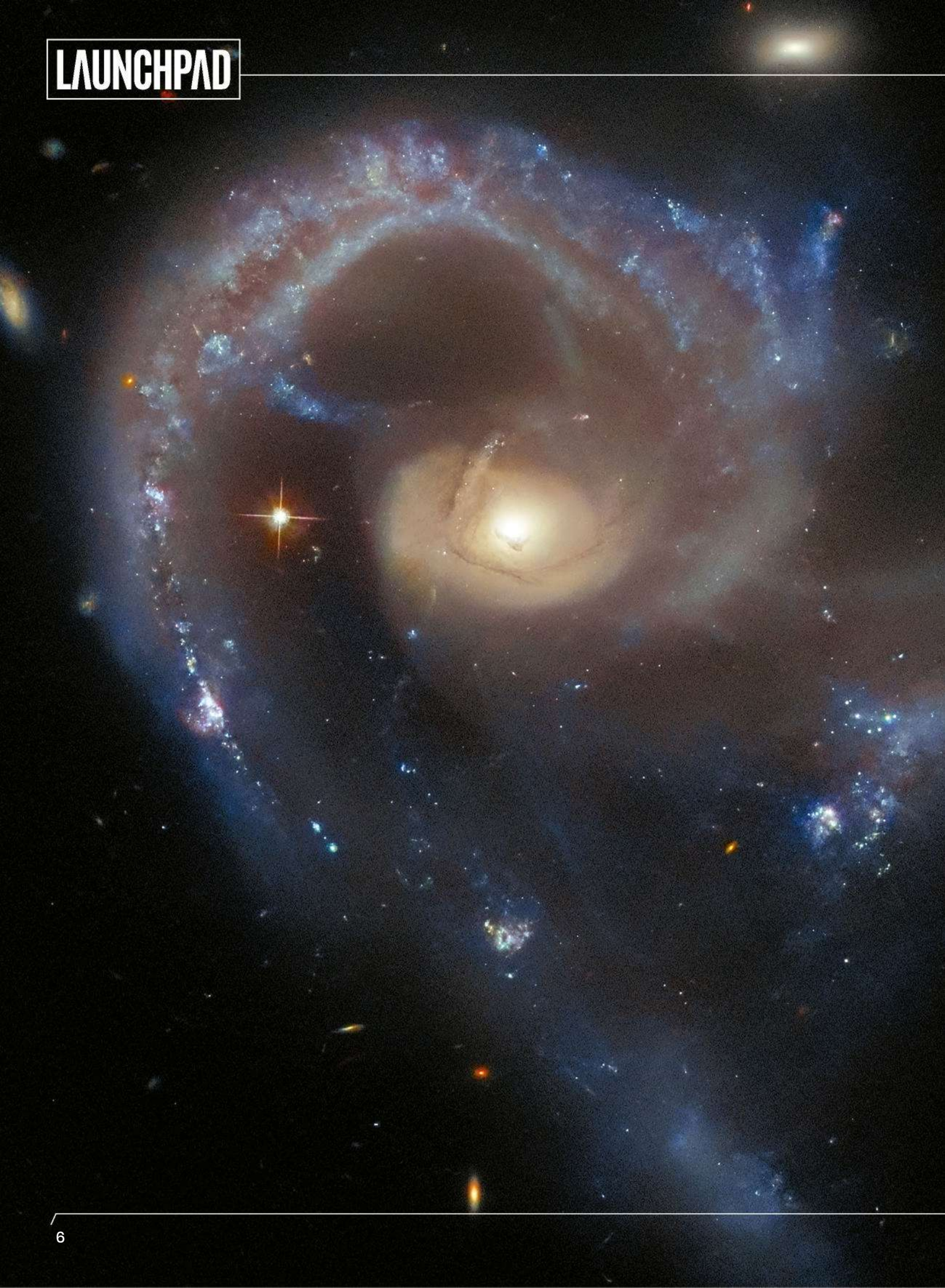

18 September 2023

## Intergalactic bridge connects a galactic smash-up

A faint 'bridge' of gas connects two colliding galaxies in a new photo from the Hubble Space Telescope. The Arp 107 system includes a pair of galaxies that are in the process of merging. Located about 465 million light years from Earth, the galactic duo is connected by a tenuous stream of dust and gas. Hubble, a joint mission led by NASA and the European Space Agency (ESA), snapped this new view of Arp 107 using its Advanced Camera for Surveys. The larger galaxy, captured on the left of the image, boasts one large spiral arm that curves around the galactic core. Known as a Seyfert galaxy, this cosmic realm is home to an active galactic nucleus. "Seyfert galaxies are notable because despite the immense brightness of the active core, radiation from the entire galaxy can be observed," ESA officials said. "This is evident in this image, where the spiralling whorls of the whole galaxy are readily visible."

Active galactic nuclei exhibit an intense glow associated with material falling into the supermassive black hole at the centre of the galaxy. In fact, the radiation emitted by an active galactic nucleus can outshine the combined light of every single star in its host galaxy. The galaxy's bright spiral arm is speckled with budding stars – stellar births fuelled by the abundant source of material being siphoned from the smaller companion galaxy, which can be seen to the lower right of the image.

The smaller galaxy appears to have a bright core, but relatively faint spiral arms as it's being absorbed into the larger galaxy. The stream of material connecting the merging galaxies hangs delicately beneath the pair in the new Hubble visual. Arp 107 belongs to a group of galaxies known as the Atlas of Peculiar Galaxies, which was compiled in 1966 by Halton Arp. The new Hubble photo was taken as part of a larger initiative to observe understudied members of the Arp catalogue.

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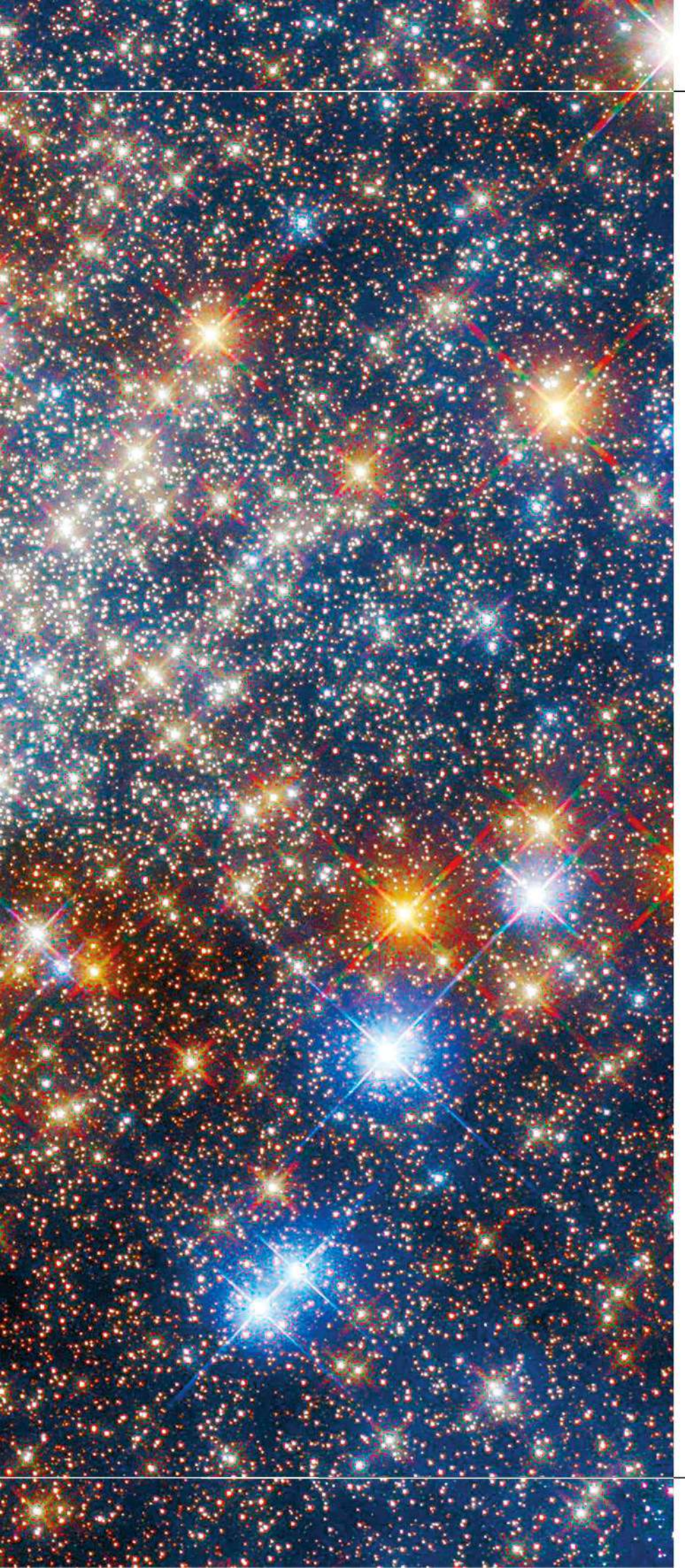


7 September 2023

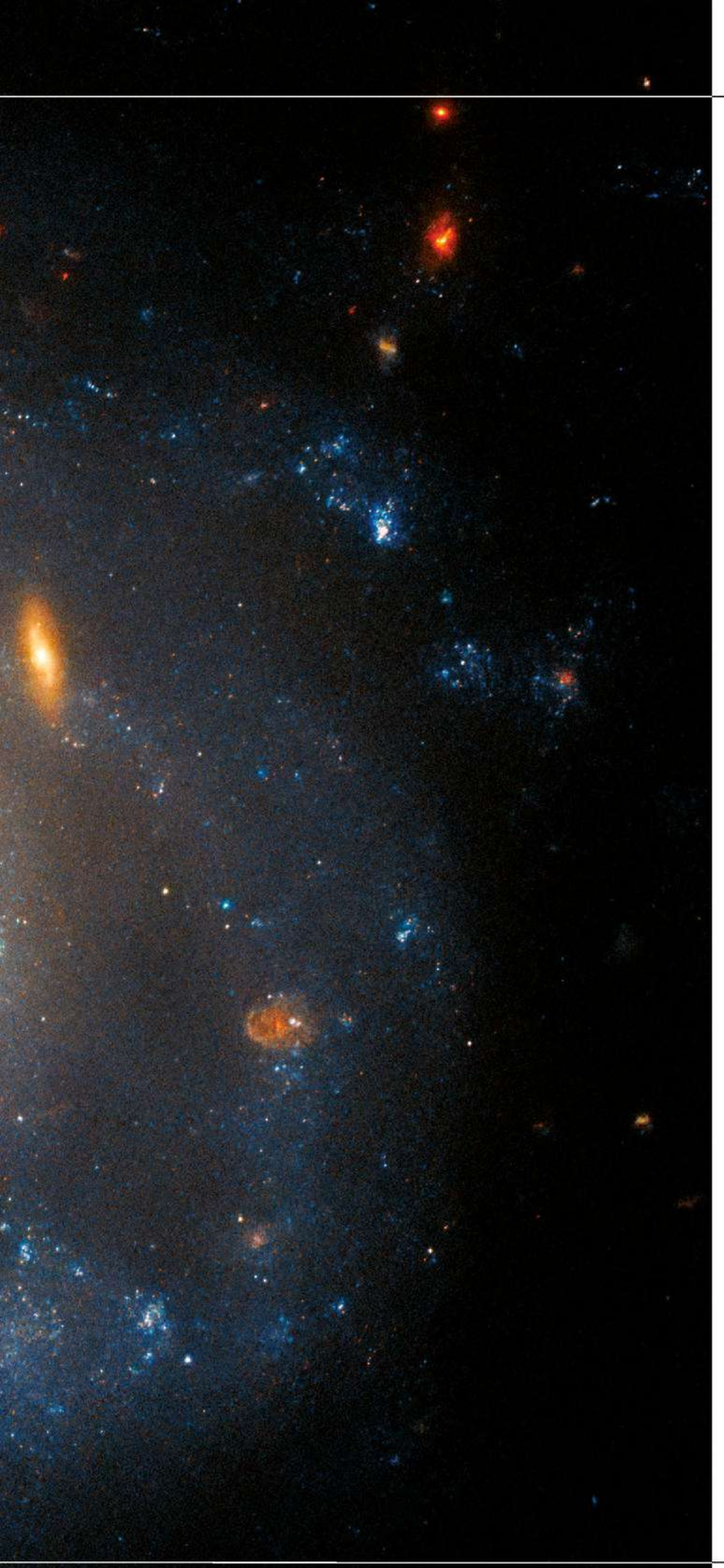
# Globular cluster glitters in a stunning new Hubble photo

A globular cluster glitters with starlight in a new photo from the Hubble Space Telescope. Located 15,000 light years from Earth, the globular cluster known as Terzan 12 is nestled deep in our Milky Way, in the constellation of Sagittarius. A globular cluster contains hundreds of thousands to millions of stars tightly bound together by gravity, causing the large structures to appear spherical when viewed from Earth.

Hubble snapped a new view of Terzan 12 shrouded in gas and dust, which absorb and alter the starlight emanating from the globular cluster. A higher concentration of stars can be seen near the centre of Terzan 12. This densely packed group shines extra bright in the new Hubble photo. "The Milky Way has about 150 ancient globular clusters at its outskirts," NASA officials said. "These clusters orbit around the galactic centre, but far above and below the pancake-flat plane of our galaxy, like bees buzzing around a hive."

In the new Hubble photo, the interstellar dust particles scatter blue light, causing only the redder wavelengths from the cluster to come through to our view. The brightest red stars in the photo are massive, ageing giants several times larger than the Sun. The bright-blue stars in the photo are not part of the cluster – they're located in the foreground of the image, unobscured by interstellar material. Hubble photographed Terzan 12 as part of an initiative to investigate the globular clusters located towards the centre of our galaxy, where, compared to the outer halo of the Milky Way, there are relatively few.

© NASA, ESA/Hubble



4 September 2023

## Lonely galaxy looms in isolation

A distant galaxy looms in lonely isolation in a new photo from the Hubble Space Telescope. The galaxy, called IC 1776, lies over 150 million light years from Earth in the constellation of Pisces. Hubble recently snapped this new view of the galaxy, capturing its irregularly shaped structure and indistinct spiral arms. "The edges are faint and the core has a pale-yellow glow. It's dotted with small, wispy, blue regions where stars are forming," ESA officials said. "A few stars and small galaxies in warm colours are visible around it."

Observations of IC 1776 suggest that the galaxy recently hosted a violent star explosion, also known as a supernova. Data from the Lick Observatory Supernova Search – a robotic telescope that scours the night sky in search of transient phenomena such as supernovae – revealed remnants of the stellar explosion, named SN 2015ap, with observations collected in 2015. Hubble then followed up with observations of the supernova's aftermath as part of two different projects, both of which were designed to investigate the debris left behind by such stellar explosions. The ESA shared Hubble's latest view of IC 1776, the galaxy in which the supernova SN 2015ap occurred, on 4 September. "A variety of telescopes automatically follow up the detection of supernovae to obtain early measurements of these events' brightnesses and spectra," ESA officials said. "Complementing these measurements with later observations which reveal the lingering energy of supernovae can shed light on the systems which gave rise to these cosmic cataclysms in the first place."

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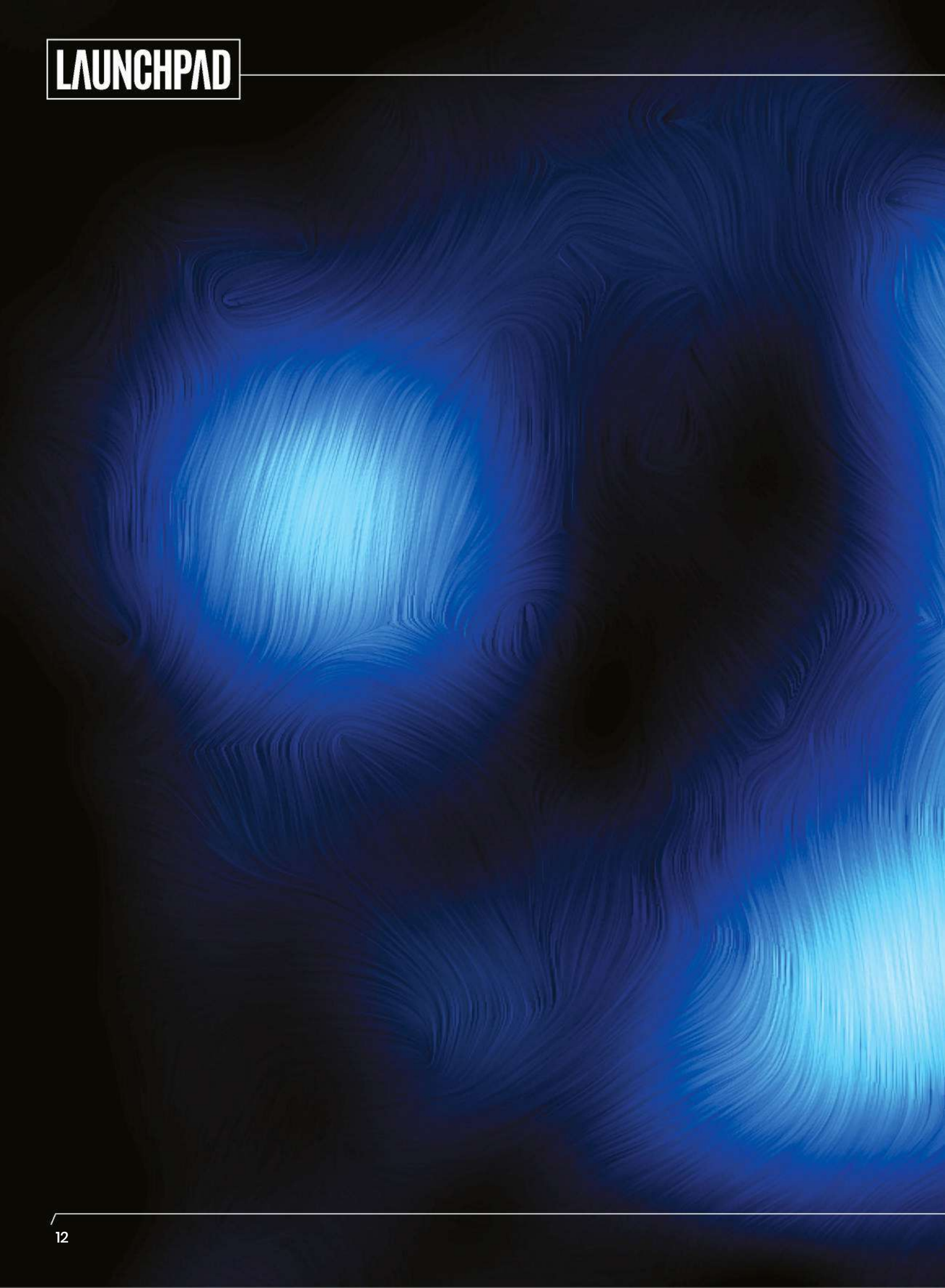


6 September 2023

# The earliest magnetic galaxy ever detected offers clues about the Milky Way's history

A magnetic field 16,000 light years across has been detected in an ancient galaxy from which light is being magnified by a gravitational lens. Because it sits so far away from us, we're seeing this galaxy as it was when it existed over 11 billion years ago. While all galaxies contain a giant magnetic field, astronomers have never detected galactic magnetism this early in the universe before. The discovery was made with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile by a multinational team of astronomers led by Jim Geach of the University of Hertfordshire.

The galaxy, ASW0009io9, was discovered in 2014 as part of a citizen science project called Space Warps, launched in the UK in conjunction with the TV show *Stargazing Live*. The project resulted in 7.5 million classifications of lensed galaxies in images taken by the Canada-France-Hawaii Telescope Legacy Survey. The galaxy's magnification is distorted, appearing as what's known as an Einstein ring. This is a phenomenon that occurs when the distant galaxy, the lensing foreground object and Earth are all in nearly perfect alignment across billions of light years.

Geach, who spearheaded observations of 9io9 in 2014, has led a team in using ALMA to detect emitted light from interstellar dust grains, which often contain metals, in the distant galaxy. These dust grains are aligned to the galaxy's magnetic field. This alignment results in the polarisation of the long-wavelength light emitted by the dust. When light is polarised, it means the photons are oscillating in a preferred direction. It's a bit like looking at the galaxy with sunglasses, which permit only light of a certain polarisation to pass through them.

All galaxies, including our own Milky Way, contain a widespread magnetic field that's woven into the fabric of a galaxy's clouds of molecular gas and dust. However, the origin of these magnetic fields is a mystery. 9io9 tells astronomers that however they form, they must do so relatively early and rapidly.

© ESA

# A giant moon collision may have given rise to Saturn's iconic rings

Reported by Tereza Pultarova

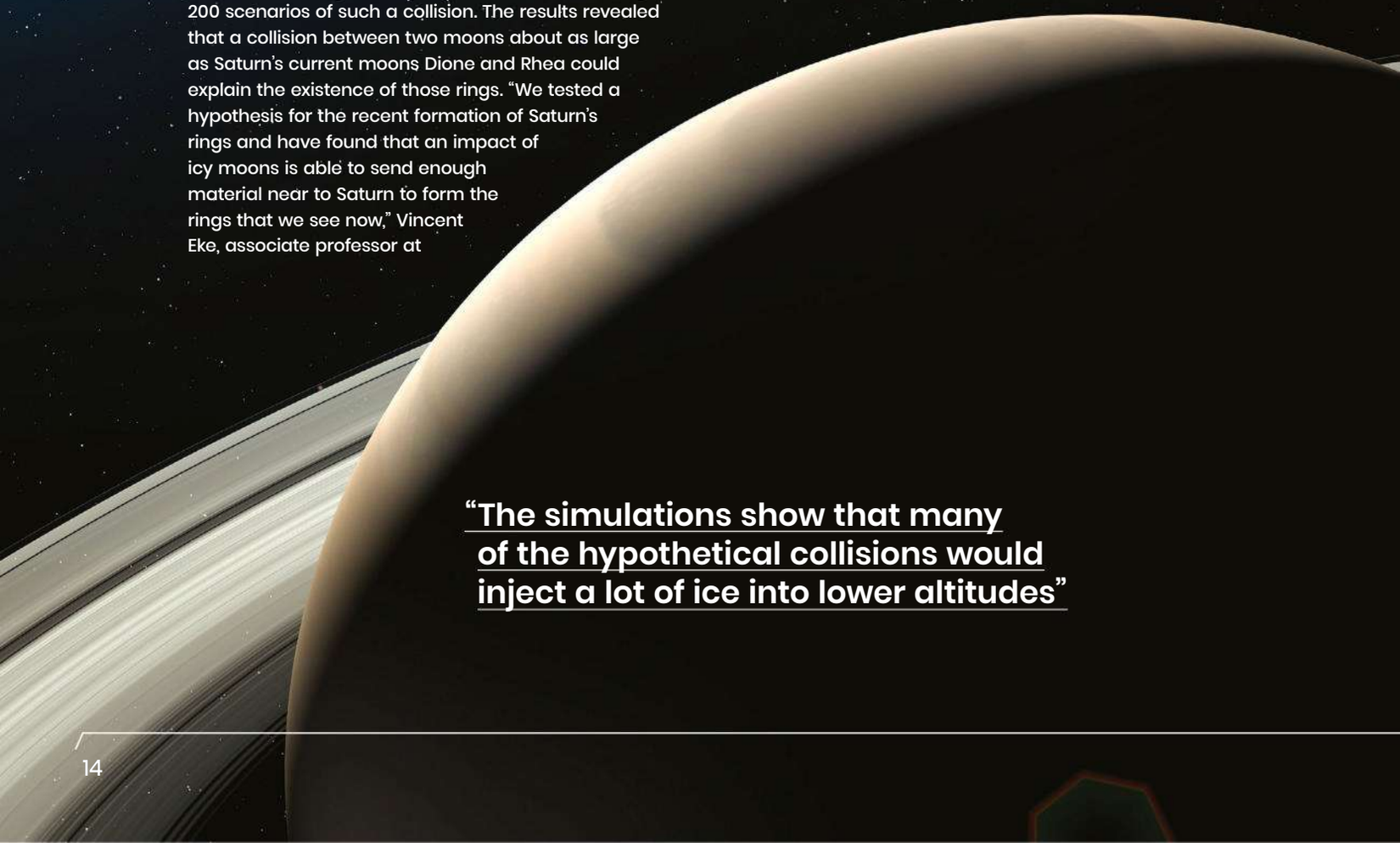
A collision between two ancient icy moons that may have once orbited Saturn could have given rise to the planet's iconic ring system. Saturn is probably the most eye-catching planet in the Solar System, but it may also be one of the most mind-boggling. Surrounded by a series of seven concentric rings and orbited by an army of at least 145 moons, the gas giant, second in size only to Jupiter, has puzzled astronomers for centuries.

But a new study may have found an answer to one of Saturn's mysteries – the origin of its rings. The study, based on dozens of computer simulations, used data collected by NASA's Cassini mission that orbited Saturn for 13 years between 2004 and 2017. The probe found the material that makes up the rings, first observed by Galileo Galilei in 1610, consists of icy fragments that are very pristine and unpolluted by dust. Those Cassini findings suggested that the iconic rings of Saturn must be fairly young, only a few million years old, and that for the majority of the Solar System's 4.5 billion-year history, Saturn looked much more bland.

The researchers behind the new study, a team consisting of experts from NASA and Durham University, speculated that the rings may have formed from a relatively recent collision of two ancient icy moons. They used powerful supercomputers to simulate nearly 200 scenarios of such a collision. The results revealed that a collision between two moons about as large as Saturn's current moons Dione and Rhea could explain the existence of those rings. "We tested a hypothesis for the recent formation of Saturn's rings and have found that an impact of icy moons is able to send enough material near to Saturn to form the rings that we see now," Vincent Eke, associate professor at the Institute for Computational Cosmology at Durham University, said.

Although the rings are made almost purely from ice, scientists think that Saturn's icy moons have rocky cores. The simulations confirmed that the icy fragments and the rocky bits would scatter in different ways after a collision, allowing the rocks to coalesce into new moons, while the ice would get dispersed in orbits closer to Saturn's surface. Rings can only form around celestial bodies within the Roche limit, a boundary where the gravity of the orbiting material is weaker than the tidal forces of the body it orbits.

The simulations show that many of the hypothetical collisions would inject a lot of ice into lower altitudes while the rocks would clump together in higher orbits. "This scenario naturally leads to ice-rich rings because when the progenitor moons smash into one another, the rock in the cores of the colliding bodies is dispersed less widely than the overlying ice," Eke said. Saturn's ice-covered moons are of great interest to scientists as some of them, such as the tiny Enceladus, might harbour conditions suitable for the emergence of simple life. There is still a lot that scientists don't know about Saturn and its past, and the results of this study are only a small step towards cracking the planet's mysteries.



"The simulations show that many of the hypothetical collisions would inject a lot of ice into lower altitudes"

Saturn has puzzled astronomers for centuries

An artist's impression of a quasar

# Thousands of active red galaxy hearts with powerful radio signals have been discovered

Reported by Tariq Malik

Red quasars filled with cosmic dust produce stronger radio emissions than their bluer, dust-free counterparts – and these phenomena could represent a generation of younger active galaxies with supermassive black holes that only recently switched into overdrive.

"There are still many unanswered questions surrounding red quasars, such as whether black hole winds or radio jets are ultimately responsible for this enhanced radio emission," Victoria Fawcett, lead author of a new study on this finding and an astronomer at Newcastle University, said. However, Fawcett believes we're getting close to the brink of fully understanding the nature of these incredible marvels.

A quasar is the powerful central region of an active galaxy driven by a supermassive black hole that is being fed huge amounts of matter. That matter forms a disc of gas around the black hole, known as an accretion disc, that reaches millions of degrees and releases fierce radiation winds. Meanwhile, magnetically collimated jets launch outwards from the disc. Quasars are so bright that they vastly outshine the collective starlight of their host galaxies, and can therefore be seen across the universe.

Most quasars appear blue – a hue caused by optical and ultraviolet emissions from the hot accretion disc. However, a fraction appear red instead. To reach their conclusions about those red quasars, Fawcett and her fellow researchers sampled approximately 35,000 quasars observed by the Dark Energy Spectroscopic Instrument (DESI) on the Nicholas U. Mayall Telescope at Kitt Peak National Observatory in Arizona.

Of this collection, Fawcett's group found 3,038 to be red quasars. Cross-referencing with radio astronomy data from the Low Frequency Array (LOFAR) Two-meter Sky Survey (LoTSS), they confirmed that most of these red ones are also emitting strongly in radio waves. The redness comes from the presence of dust, which absorbs shorter, bluer wavelengths but allows longer, redder wavelengths to pass. The red quasars must therefore be smothered in cosmic dust, formed of tiny grains just microns in size.

© ESO; Getty

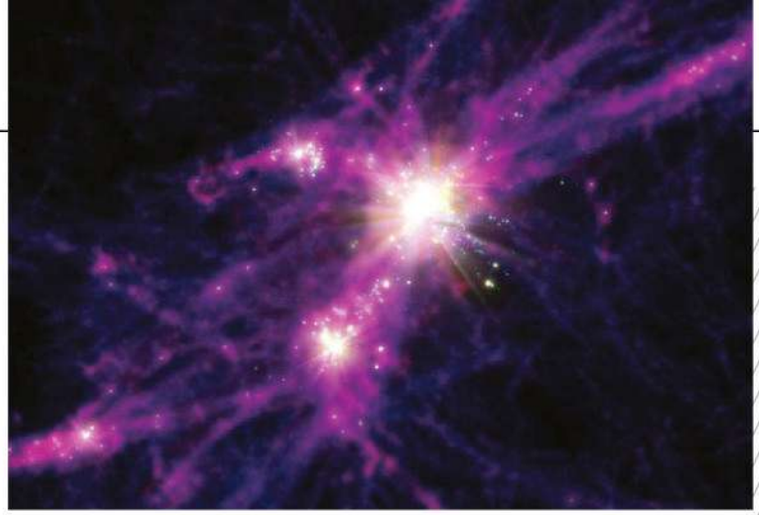
# Webb's early galaxy images are oddly bright

Reported by Tariq Malik

The bright galaxies found by the James Webb Space Telescope in the very early universe could be the product of bursts of massive star formation, and it's likely that this renders the galaxies more luminous than expected for the era in which they exist. This is the conclusion drawn by researchers who used computer simulations to model how these galaxies formed and began producing stars.

When Webb began science operations, its deep observations of the universe quickly began turning up high-redshift galaxies. These are galaxies that seemed to have existed earlier in the universe than astronomers had ever seen before. In fact, the galaxies, which were seen as they were when the universe was less than 400 million years old, appeared more luminous than predicted. This led to claims that the standard model – which depicts galaxies starting off small and then growing through mergers driven by filaments and halos of dark matter in the cosmic web – must be wrong.

"The discovery of these galaxies was a big surprise because they were substantially brighter than anticipated," Claude-André Faucher-Giguère of Northwestern University said. "Typically, a galaxy is bright because it's big, but since these galaxies formed at cosmic dawn, not enough time has passed since the Big Bang. How could these galaxies have formed so quickly?" Faucher-Giguère and his team found that rather than being big, the galaxies are luminous because they are seen when they underwent a frenzy of star formation.



An artist's impression of star-bursting galaxies in the early universe being fed the raw material for star formation through filaments in the cosmic web

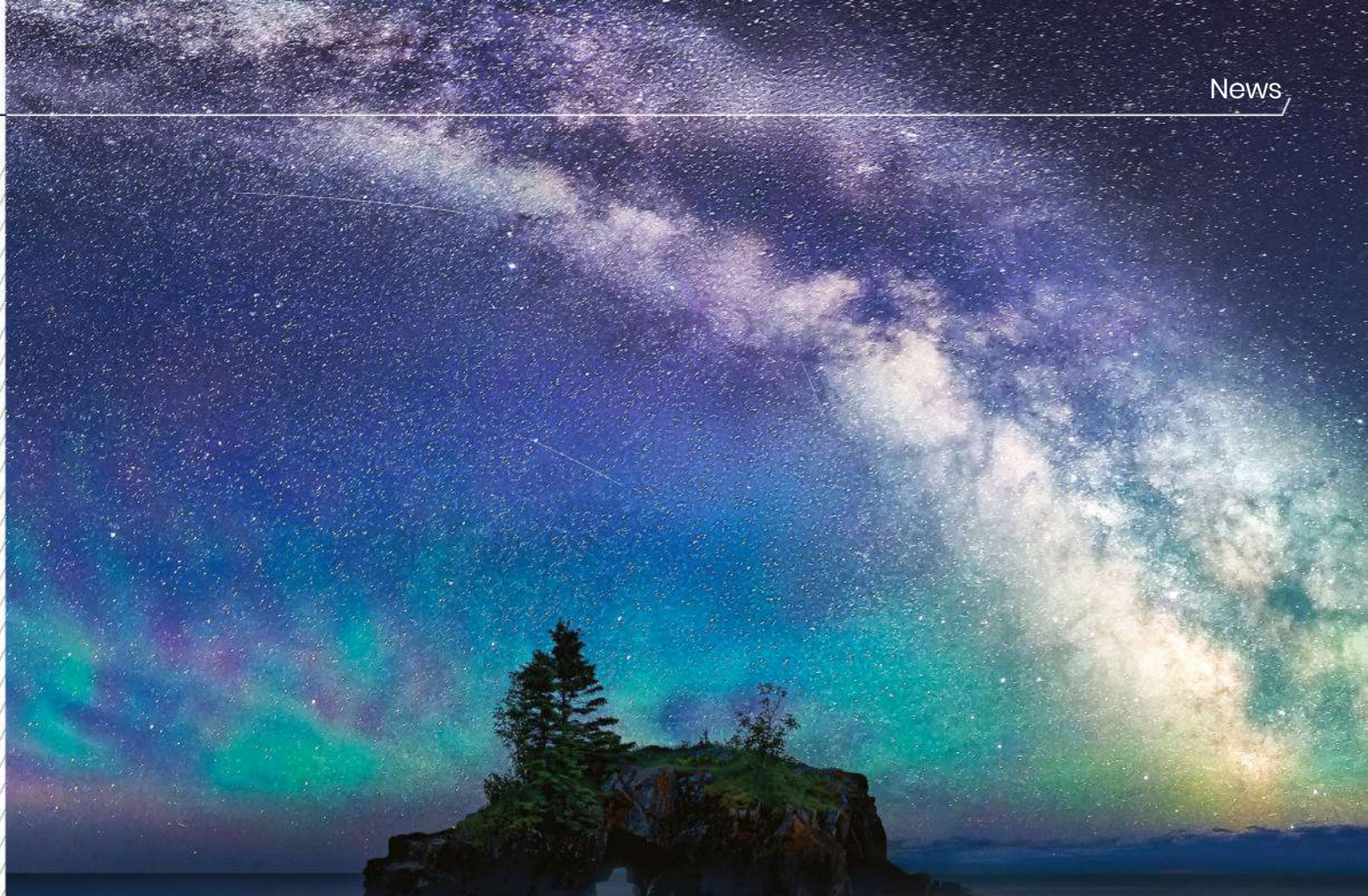
# NASA wants a 'lunar freezer' for its Artemis Moon missions

Reported by Brett Tingley

NASA has issued a request for 'lunar freezer' designs that can safely store materials taken from the Moon during planned Artemis missions. According to a request for information (RFI) posted to the federal contracting website **sam.gov**, the freezer's primary use will be transporting scientific and geological samples from the Moon to Earth. These samples, the post specifies, will be ones collected during the Artemis program. The post also states that the lunar freezer could be used to store and transport "human biological and physiological samples collected during the missions," presumably for analysing how spaceflight to the Moon affects astronauts.

NASA writes that it wants the lunar freezer ready by the end of 2027 to be launched aboard its planned Artemis V mission. To make the long journey back to Earth from the Moon's surface, the lunar freezer should be transportable aboard the vehicles, facilities and spacecraft that future Artemis astronauts will use. These include the future lunar rover, any Moon habitats, the Human Landing System (HLS), the Orion crew module and the Gateway lunar outpost. It must therefore be able to withstand physical forces encountered during launch and landing, such as vibrations and shocks. The freezer should maintain a temperature of -121 degrees Fahrenheit (-85 degrees Celsius) for at least 30 days.

Artist's illustration showing Artemis astronauts exploring a site near the Moon's south pole



# The Milky Way is warped, and it might be the work of dark matter

Reported by Robert Lea

The Milky Way is twisted, and astronomers may finally know why. They're laying the blame on a tilted halo of dark matter that envelopes our galaxy. The common image of our galaxy resembles a flattened disc similar to a vinyl record, but what you might not imagine is the flared skirt at its edge, structured like the outer ring of a frisbee. And when scientists have studied the shape of the Milky Way in great detail, they found the disc of our spiral galaxy to also have a warp, meaning it's a bit closer to a frisbee that's been twisted and bent.

These features have remained mysterious for quite a while, but now astronomers from the Center for Astrophysics, Harvard and Smithsonian, have performed calculations that indicate the halo of dark matter enveloping the Milky Way could be 'off-kilter', and this could be causing the flared edge and warped shape of our galaxy. Not only might this revelation help us better understand the evolution of the Milky Way, it could also reveal more about the nature of dark matter and how it shapes the overall development of galaxies.

Dark matter is a challenge for scientists to explain because it doesn't interact with light, making it effectively invisible. The only way scientists have been able to infer the presence of dark matter is via its interactions with gravity and the influence this has on everyday matter and light. Dark matter is the gravitational glue that holds galaxies together. Thus researchers have deduced that most, if not all, galaxies are wrapped in a halo of dark matter. And for the Milky Way that halo of dark matter is thought to extend out past the halo of stars surrounding the galaxy's main disc and central galactic nucleus.

Last year, the same team was able to calculate the Milky Way's stellar halo to hold an elliptical shape, angled at a tilt relative to the galaxy's main disc. The team has now built upon that by using computer models to calculate that the orbit of those stars fits within a tilted, elliptical dark matter halo. This turned out to be a near-perfect match of the Milky Way with its flared edge and its warp.

"A tilted dark halo is actually fairly common in simulations, but no one had explored its effect on the Milky Way," Charlie Conroy, team member and a professor of astronomy at the Center for Astrophysics, said. "It turns out that the tilt is an elegant way to explain both the magnitude and direction of our galaxy's wobbly disc." The team's findings also support the idea that the Milky Way has grown as a result of collisions with other galaxies.

The Milky Way is twisted, but is dark matter to blame?

© NASA; Getty

Pluto illustration incorporating NASA New Horizons terrain imagery

# NASA extends the New Horizons mission through the late 2020s

Reported by Mike Wall

NASA's New Horizons spacecraft will be able to keep exploring its exotic environs for at least another five years. The space agency announced on 29 September that it will keep New Horizons' lights on while it's still zooming through the Kuiper Belt, the expansive ring of icy bodies beyond Neptune's orbit. "The New Horizons mission has a unique position in our Solar System to answer important questions about our heliosphere and provide extraordinary opportunities for multidisciplinary science for NASA and the scientific community," Nicola Fox, associate administrator for NASA's Science Mission Directorate in Washington, said. The heliosphere is the big bubble of magnetic fields and charged particles that the Sun blows around itself. Beyond it lies interstellar space. "The agency decided that it was best to extend operations for New Horizons until the spacecraft exits the Kuiper Belt, which is expected in 2028 through 2029," Fox added.

The New Horizons spacecraft launched in January 2006 on a long-duration mission to provide the first-ever up-close look at Pluto, the Kuiper Belt's most famous resident and former planet. The spacecraft delivered, zooming past the dwarf planet in July 2015 and revealing a world of stunning diversity and beauty. And the probe kept cruising along on an extended mission that centred on a flyby of another Kuiper Belt object (KBO) – the 34-kilometre (21-mile) wide Arrokoth. That encounter went swimmingly as well, returning great imagery and intriguing science. For example, New Horizons' observations suggest that Arrokoth formed via a very gentle merger of two smaller objects.

But the mission's future became murky this year. NASA extended New Horizons' mission through 2024, but proposed a big shift after that – a move to the heliophysics division from planetary science. New Horizons' principal investigator, Alan Stern, objected to this idea, arguing that the best scientific return would come from staying the course, allowing the probe to continue studying the little-explored Kuiper Belt. The mission extension appears to be a compromise of sorts. It will be funded primarily by planetary science but jointly managed by that division and heliophysics.

Beginning in 2025, New Horizons will focus on gathering heliophysics data – but team members can still hold out hope for another KBO encounter. "While the science community is not currently aware of any reachable Kuiper Belt object, this new path allows for the possibility of using the spacecraft for a future close flyby of such an object, should one be identified," NASA officials added. "It also will enable the spacecraft to preserve fuel and reduce operational complexity while a search is conducted for a compelling flyby candidate." Stern seems happy to have secured at least five more years of New Horizons operations. "I want to thank everyone who supported us in getting #NASA to continue the exploration of the Kuiper Belt by its @NASANewHorizons spacecraft – you did it!" he wrote online on 1 October.

NASA spent $9.5 million (around £7.8 million) on New Horizons in fiscal year 2022. The agency is still working on how to pay for the mission's next five or so years. "As a starting point, funding within the New Frontiers program will be rebalanced to accommodate extended New Horizons operations, and future projects may be impacted," NASA officials said. New Frontiers is NASA's program of medium-cost missions; New Horizons was the first New Frontiers project to get off the ground. Additional extensions are possible if the resources and will are there, as New Horizons has enough nuclear fuel remaining to continue flying through at least 2040, mission team members have said.

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# WIN AN OLIVON PC-3 10x56 BINOCULAR WORTH £349!

## Embark on a fuss-free tour of the night sky with this month's competition prize

Ideal for those who are just breaking into the hobby of astronomy or those looking to add to their existing kit for a fuss-free observing experience, the Olivon PC-3 10x56 binocular offers splendid views of the universe and wildlife. Featuring BaK4 prisms along with a silver coating, this rugged, easy-to-handle binocular delivers exceptionally crisp, clear and bright views of a selection of targets, from the surface of the Moon and the naked-eye planets to star clusters and bright nebulae. Equipped with a rubber coating and filled with nitrogen gas, the Olivon PC-3 10x56 is able to withstand observations in a variety of locations and weather conditions, making the binocular versatile and suitable for any occasion.

To be in with a chance of winning, answer this question:

**In which constellation would you be able to find globular cluster Messier 14?**

**A:** Ophiuchus (the Serpent Bearer)
**B:** Ursa Major (the Great Bear)
**C:** Taurus (the Bull)

**Competition ends on 29 November 2023**

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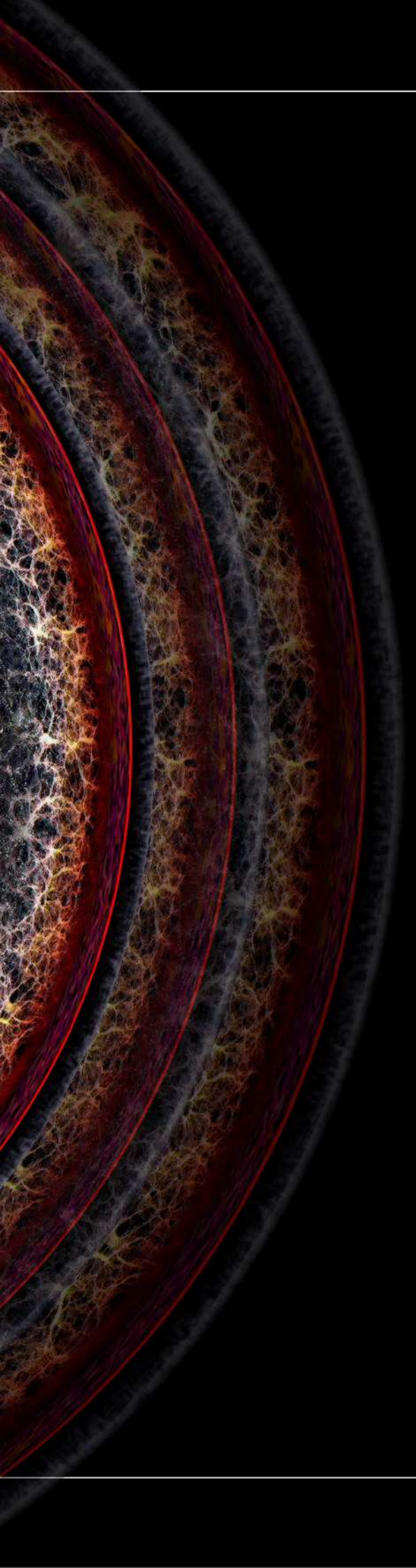
HUBBLE VS WEBB
EXPANSION
OF THE
UNIVERSE



## New theories and observations are shedding light on the very beginnings of the universe and the formation of the first stars and galaxies. But they're also revealing unexpected mysteries

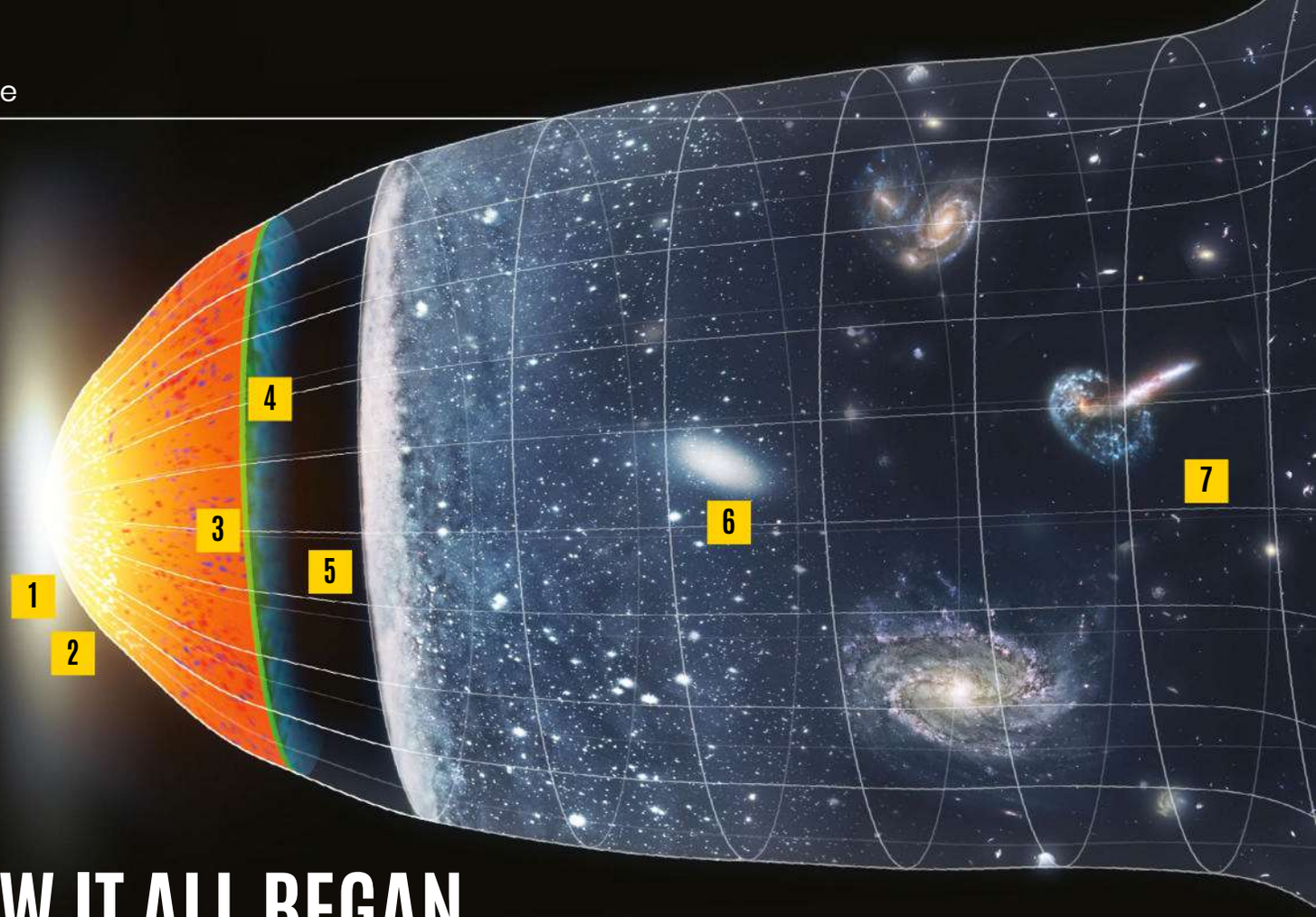
Reported by Giles Sparrow

Ask any astronomer about the very beginnings of the universe and they're likely to describe the Big Bang theory. Some 13.8 billion years ago, the universe was born out of nothing in an explosion that unleashed the expanding dimensions of space and time, alongside vast amounts of energy. In the moments that followed, most of this energy transformed into the building blocks of matter – subatomic particles of varying mass and complexity that eventually came together to form simple atoms and then coalesced to create giant, short-lived stars and the nuclei of the first galaxies.

There's a wealth of evidence to show that the Big Bang theory is broadly correct. Even today the universe is still growing at tremendous speed, with widely separated galaxies and galaxy clusters being pulled apart as the space between them expands. What's more, when powerful telescopes focus on the galaxies farthest from Earth, whose light set out on its journey towards us many billions of years ago, they see violent star systems still in the process of formation. Most tellingly of all, the entire universe is filled with the weak 'afterglow' of the Big Bang itself – the cosmic microwave background (CMB) radiation that comes from all over the sky and is otherwise inexplicable. But even if the basics of the Big Bang are well established, that doesn't mean there aren't still questions to answer. The biggest mysteries lie at either end of the process: at the moment when space and time were supposedly 'created' and a few hundred million years later, in the period when the first stars and galaxies began to form.

On 25 December 2021, NASA's enormous James Webb Space Telescope blasted off on a European Space Agency Ariane V rocket with a mission to answer at least some of these big questions. Webb's vast mirror is designed to capture infrared radiation with longer wavelengths – and less energy – than visible light. This includes radiation from the most distant, and therefore earliest stars and galaxies, emitted as visible light but stretched into the infrared during its long journey across ever-expanding space. This shifting of light into the infrared means the earliest period of cosmic evolution is beyond the limits of instruments such as the Hubble Space Telescope, which work mostly in visible light, so Webb is bringing a whole generation of early galaxies into view, with surprising results.

Source: Wikipedia Commons © Pablo Carlos Budassi




# HOW IT ALL BEGAN

**1 The Big Bang**
The event that's said to have created time and space is thought to have occurred some 13.8 billion years ago. Here the universe was infinitely hot and dense.

**2 Inflationary bounce**
Within the first fraction of a second, the infant universe was blown up by inflation. Tiny fluctuations in the distribution of energy were blown up to an enormous scale.

**3 Expanding fireball**
For 380,000 years, matter remained so dense that the universe was 'foggy'. Interactions with radiation kept normal matter particles extremely hot and prevented them from forming structure.

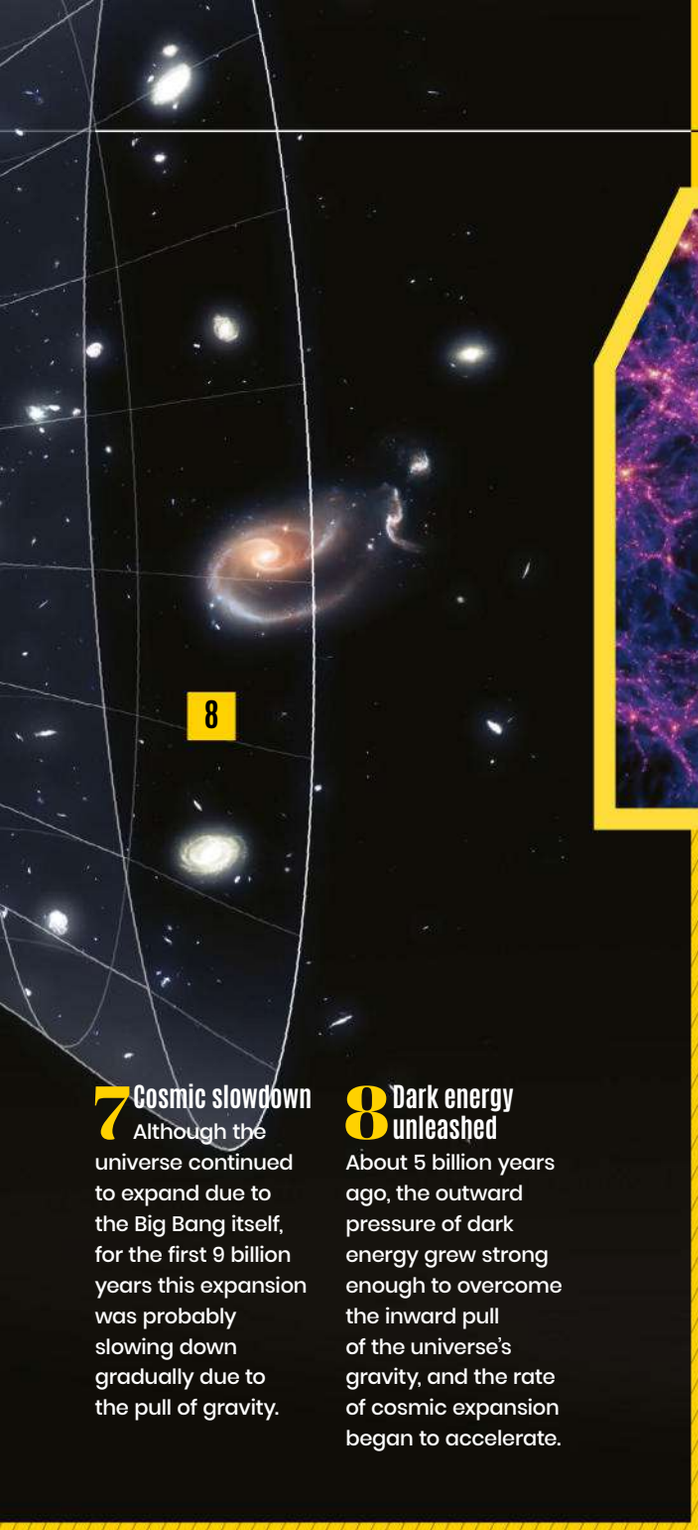
**4 Afterglow**
When the universe finally became cool enough for subatomic particles to form atoms, the number of particles in space fell dramatically and the universe became transparent.

**5 Cosmic dark age**
For a few hundred million years the universe was dark as normal matter coalesced around the seeds of structure formed by dark matter. Eventually, matter became dense enough to form the first giant stars.

**6 Galaxy formation**
The first galaxies formed around black holes left by early stars. Most theories predict that they started out very small and grew through repeated mergers.

Astronomers have long assumed that galaxies develop in size and shape over time. Large spiral galaxies like our Milky Way are thought to have developed their structure after countless mergers between smaller irregular galaxies, while huge balls of stars known as elliptical galaxies appear to be the result of mergers and collisions between spirals. For this reason and others, the first galaxies that formed are assumed to have been very small, lightweight and faint. Yet when Webb trained its arsenal of instruments on a small patch of sky close to the famous Big Dipper star pattern for many hours, it revealed something surprising. Hidden within the 'deep-field' image, Dr Erica Nelson of the University of Colorado Boulder found half a dozen galaxies that were both extremely red, and therefore distant and very early in cosmic history, but unusually bright. If the brightness of the galaxies is a good indication of their mass, then it seems that some of these bright early galaxies could be as heavy as our own Milky Way. "It's bananas," says Nelson. "You just don't expect the early universe to be able to organise itself that quickly. These galaxies should not have had time to form."

The discovery is so surprising, in fact, that some astronomers have nicknamed the new discoveries 'universe breaker' galaxies. That's because they threaten to undermine a highly successful model used for understanding large-scale cosmic evolution. Known as Lambda-CDM, this model balances the strength of dark energy,



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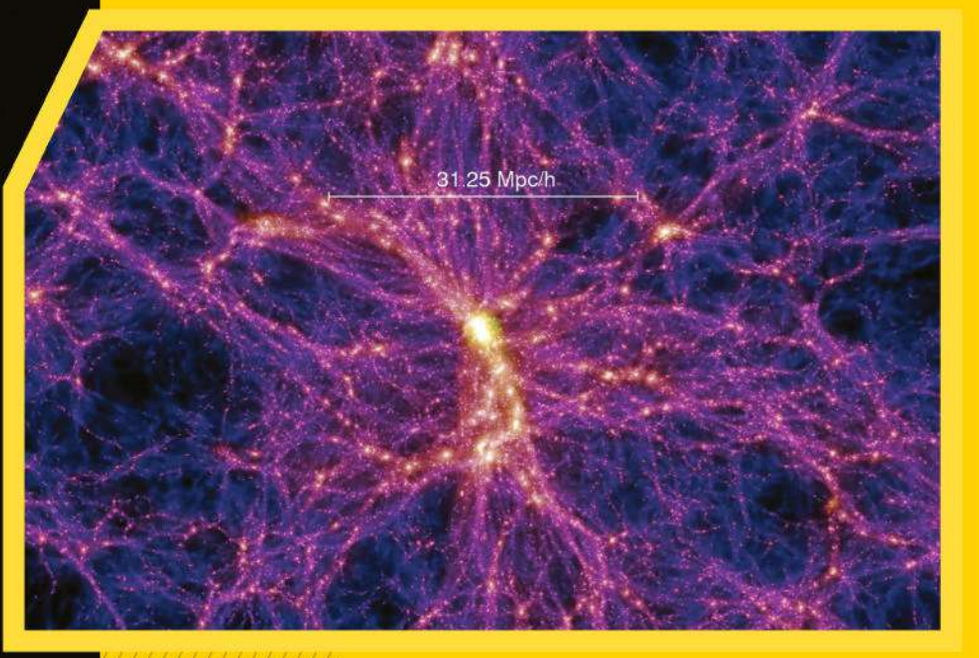
**7 Cosmic slowdown**
Although the universe continued to expand due to the Big Bang itself, for the first 9 billion years this expansion was probably slowing down gradually due to the pull of gravity.

**8 Dark energy unleashed**
About 5 billion years ago, the outward pressure of dark energy grew strong enough to overcome the inward pull of the universe's gravity, and the rate of cosmic expansion began to accelerate.




▲ A computer simulation shows visible matter (yellow) being drawn towards concentrations of dark matter seeded in the early universe

▼ Webb's first long-exposure, wide-field images show some of the earliest and most distant galaxies ever seen

a mysterious force that controls the rate of expansion of space, represented by the Greek letter lambda, against the gravitational attraction of 'cold dark matter' – the invisible and transparent material that vastly outweighs normal matter in the universe and can only be detected through its gravitational influence. Dark matter's unusual properties allowed it to begin coalescing and forming structures within the expanding incandescent fireball of the early universe at a time when normal matter was still unable to clump together. The result was a pattern of tiny variations in the density of the universe, or 'ripples', imprinted on the CMB that escaped across space as the fireball cleared about 380,000 years after the Big Bang. In the long 'cosmic dark age' that followed, gravity from the ripples attracted the normal matter that eventually formed the first stars and galaxies.

Computer simulations have demonstrated that with certain parameters for the behaviour of both dark energy and dark matter, Lambda-CDM results in a universe very like the one we see today. However, the model also predicts that an early generation of small galaxies took a billion years or more to merge and form more substantial systems. A recent study by Dr Mike Boylan-Kolchin, an associate professor at the University of Texas at Austin, showed that the massive galaxies seen by Webb push at the uppermost limits of what's permitted by Lambda-CDM. He also predicts that many more 'universe breakers' are likely to be discovered elsewhere in the sky. "If the masses are right, then we are in uncharted territory," Boylan-Kolchin says. "We'll require something very new about galaxy formation or a modification to cosmology."

One way to solve the puzzle would be if the rules of galaxy formation were somehow different in these ancient times; if early galaxies incorporated much more of their available matter into stars, this would allow them to appear brighter even if they were relatively small and lightweight by today's cosmic standards. "Another possibility is that these things are

© NASA; Springel et al.

Studies suggest that galaxies grow in size and complexity through collisions and mergers

The singularity hidden inside a black hole is a point where the laws of physics break down

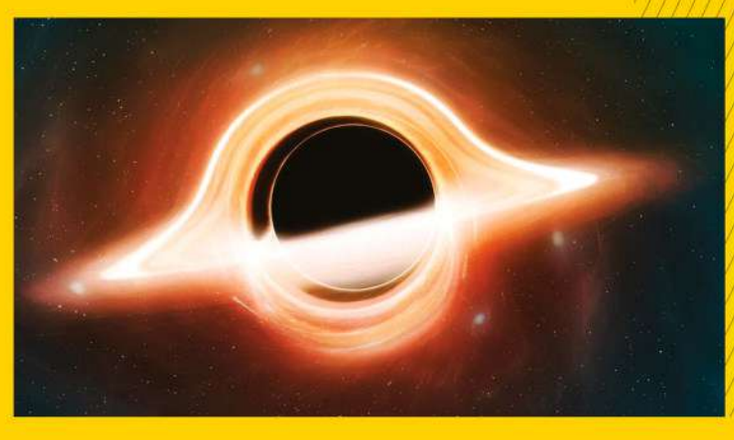
a different kind of weird object, such as faint quasars," suggests Nelson. In this scenario, the galaxies' excess brightness would be due not to their stars, but to the activity of supermassive black holes within them feeding on gas and dust from their immediate surroundings and emitting radiation in a similar but much more restrained way to the violent active galaxies known as quasars.

One other alternative explanation for the galaxies is even more intriguing: what if it's not the brightness of the galaxies that's wrong, but our estimate of their distance based on their redness and our current model of cosmic expansion? "One of the most extreme possibilities is that the universe was expanding faster shortly after the Big Bang than we predict," says Boylan-Kolchin, "which might require new forces and particles."

Could there be something wrong with our understanding of the behaviour of space itself in the early universe? While this is only one possible solution to the curious Webb observations, some theoretical cosmologists working at the other end of the Big Bang story have recently been wondering the same thing. A long-standing problem with the traditional Big Bang theory is the idea that in its first moment, the universe was a singularity – a single, infinitely dense point in space out of which everything emerged. Singularities are points at which the mathematics of general relativity, which describes the relations between space, time and matter, break down completely. "The modern interpretation of singularities in general relativity is that they represent a breakdown of the theory, and therefore they need to be avoided," says Dr Marco Bruni of the University of Portsmouth's Institute of Cosmology and Gravitation.

One possible way around this problem preoccupied Stephen Hawking in the later decades of his career and is the subject of a new book, *On the Origin of Time*, by his long-time collaborator Professor Thomas Hertog. Hawking and Hertog concluded that, due to its tiny scale, the early universe can only be understood through the equations of quantum physics. This would make the first moments of the universe inherently unpredictable, but might also cause space and time to 'blend together'. If you could wind the clock back, you would find time itself becoming increasingly space-like and running ever more slowly, until the universe became static and timeless without ever quite reaching the point of singularity. Along with graduate student Molly Burkmar, however, Bruni has been investigating another intriguing possibility: "We instead replace the singularity with a bounce within general relativity, using the negative pressure of dark energy," they explain.

Bruni and Burkmar's study was inspired in part by the similarities between inflation – a phenomenon that drove violent expansion very shortly after the Big Bang – and the dark energy that, after apparently remaining dormant, has caused the expansion of the universe to speed up once again in the past 5 billion years or so. Inflation is a core element of the modern Big Bang theory – an event in which one small fragment of the infant universe blew up to enormous size, magnifying tiny quantum fluctuations within it until they were large enough to become the seeds of large-scale structures in the later universe before coming to an end just as suddenly as it began. "Dark energy causes the expansion of our universe to accelerate," Burkmar and Bruni say. "It has negative pressure, and therefore can make gravity repulsive, rather than attractive. In general,



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anything that has a negative enough pressure plays the role of a dark energy and can evolve with time. The similarity between inflation and the current dark-energy-dominated period is that the expansion of the universe is accelerating in both cases."

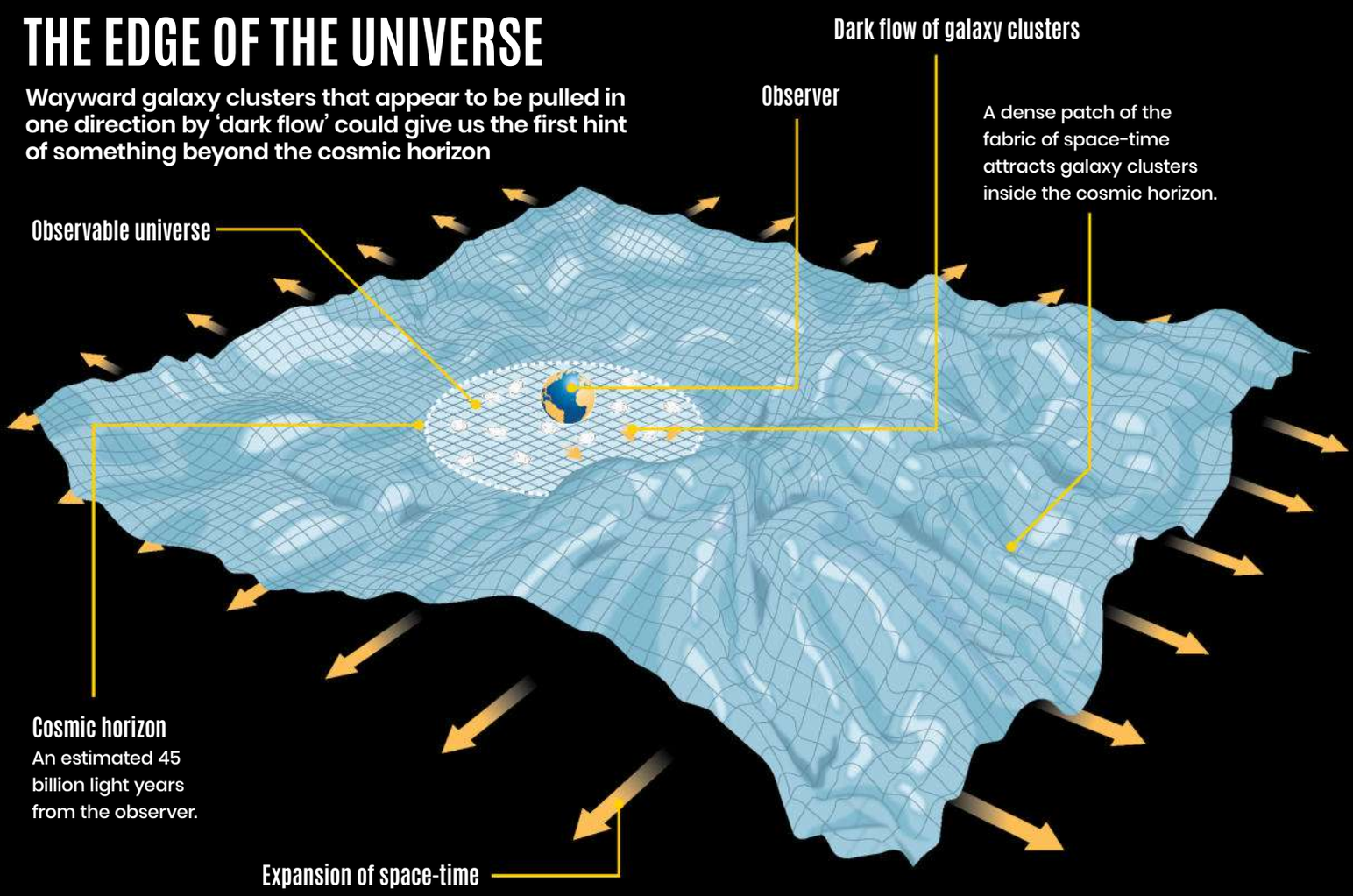
Inspired by this similarity, the cosmologists set out to look at how the universe might evolve in a situation where the pressure from dark energy could change dramatically at different points in cosmic evolution. "Our research involved analysing the consequences of Einstein's [general relativity] equations in the presence of a dark energy that can evolve between a maximum and a minimum value," they explain. "During the contraction of the universe, the dark energy increases... so the size of the universe reaches its minimum and bounces. Then the universe expands, and the dark energy decreases towards its minimum. When the dark energy is close to its maximum or minimum, the universe accelerates, [growing or shrinking rapidly]. Therefore, in our model, this dark energy explains both the bounce [of inflation] and the observed accelerated expansion today."

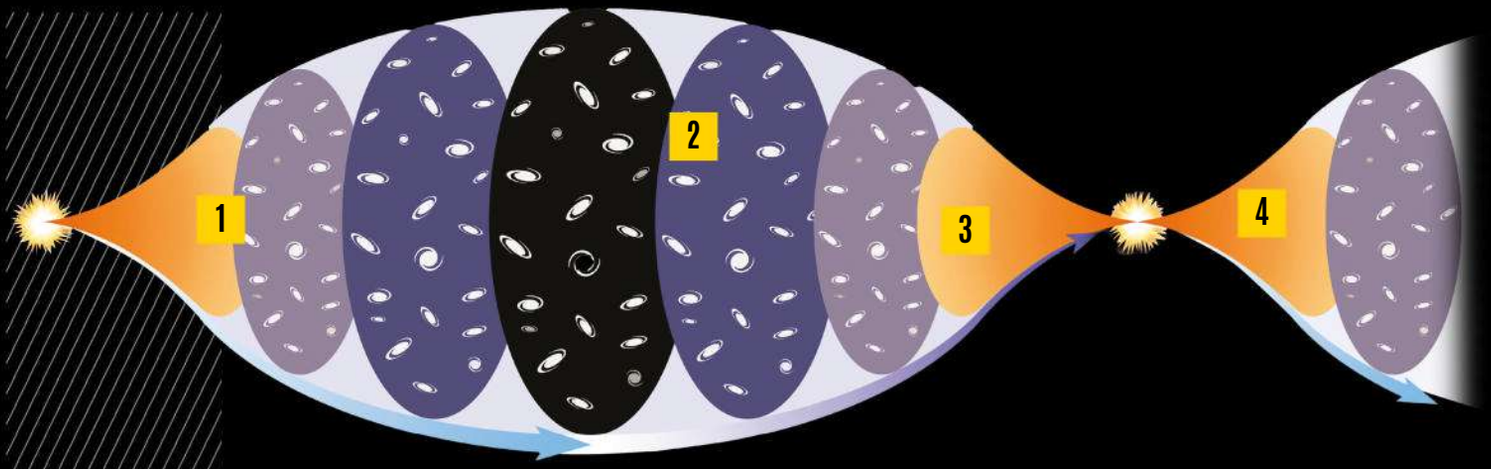
Bruni and Burkmar's work stands in contrast to other models that treat inflation as a separate phenomenon from dark energy and require space to have new exotic properties in order to explain how it was triggered and why it went away. What's more, if inflation did not mark a beginning, but a 'bounce', it opens up the possibility that our universe is just the latest iteration in a potentially infinite series extending to the past and future. Today's cosmos emerged from a previous bounce, and one day the changing influence of dark energy will reverse its current expansion, drawing everything back to another bounce in the far future. It's an intriguing idea – though there's one important limitation. In order for the bounce to work, space itself has to have a 'positive curvature'. That is, there must be enough mass and energy in the universe to eventually bring cosmic expansion to a halt – something that's far from certain.

But what would conditions within the 'bounce' itself be like? Bruni and Burkmar emphasise that it still has to take place at a point where the universe is extremely compact and very, very hot. "[It] necessarily has to occur at a high enough energy that all the standard physical processes

## THE EDGE OF THE UNIVERSE

**Wayward galaxy clusters that appear to be pulled in one direction by 'dark flow' could give us the first hint of something beyond the cosmic horizon**


Dark flow of galaxy clusters
Observer
A dense patch of the fabric of space-time attracts galaxy clusters inside the cosmic horizon.
Observable universe
Cosmic horizon
An estimated 45 billion light years from the observer.
Expansion of space-time




# ARE WE IN A BOUNCING UNIVERSE?

**1 Inflation**
Very early in the current universe, something drove rapid expansion called inflation. The bouncing universe theory suggests this was the pressure of dark energy, which later diminished in strength.

**2 Contracting universe**
According to the theory, the strength and direction of dark energy can oscillate; in the far future, it could effectively reverse, causing space to contract.

**3 Big Crunch**
As the future universe grows smaller, the strength of dark energy increases rapidly. The universe becomes hot and dense once again, and matter is transformed back into pure energy.

**4 A fresh start**
Before space collapses to a singularity, the effect of dark energy reverses and drives a new burst of inflation... the universe is reborn.

that take place in the cosmic evolution can happen," they elaborate. "The observed abundances of light elements in the universe are well explained by so-called 'Big-Bang nucleosynthesis', but this doesn't need a singularity – just a 'Big Bang' in the sense of a very high energy state where matter is hot enough for fusion of protons and neutrons into lithium, helium and so on. As for inflation, the proof in the pudding would be to work out if the accelerated phase around the bounce is long enough to produce the initial seeds for the formation of structures in the universe. This probably means that the bounce has to occur at really extreme energies."

If the universe does indeed contract back to a superdense, superhot 'Big Crunch' before each bounce, then it would erase almost every trace of its previous iteration as matter disintegrated and transformed back into pure energy in accordance with Einstein's famous equation $E=mc^2$. Indeed, the pair's calculations suggest that allowing matter or even radiation to persist during the period of reversal 'spoils' the bounce – everything must become dark energy. One thing that might survive, however, are black holes from the previous universe.

Although this 'bouncing' universe model offers a clever explanation for inflation by tying it to today's dark energy, Bruni emphasises that it doesn't attempt to explain the origin of the universe. "Inflation doesn't provide a solution for the beginning, but it leaves open the question of what happened before." It's likely to remain just that unless the pair can find concrete predictions that will allow it to be proved or disproved through observation. "That's definitely future work for Molly's PhD... The smoking gun for a bounce period could come from predicting the gravitational waves that should be produced after the bounce." As telltale distortions in space-time caused by superdense, rapidly changing objects, "these waves should be different from those produced during traditional inflation. It would then be for future gravitational-wave experiments to test the different possible bouncing models."

**Giles Sparrow**
*Space science writer*
The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.

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# LUNAR MASS DRIVER

## Future cargo delivery on the Moon

One of the arguments for colonising the Moon is that it contains a lot of material that may be useful back on Earth, such as helium-3, an isotope of helium that some say could be used as fuel in future nuclear fusion power plants to provide a huge new source of energy. If we are going to colonise the Moon, then we could do with an innovative and low-cost way to send this useful material back to Earth. After all, we don't want to have to use numerous expendable rockets to continually transport cargo to and from the Moon.

With that in mind, some space enthusiasts have envisioned a railgun of sorts that would fire projectiles from the Moon to Earth. Using magnetic levitation, it would accelerate a payload to the speed required to escape the gravity of the Moon and return to Earth. This idea was used in the 2009 movie *Moon*, with helium-3 being mined on the Moon and sent to Earth by such a machine, known as a lunar mass driver.

A lunar mass driver is essentially a long tube along which a payload is accelerated using electromagnets. Rather than relying on expendable fuel like rocket propellant, a lunar mass driver could run on solar power. The idea of a mass driver is that when a payload is accelerated to a speed greater than the escape velocity of the Moon – or 2.4 kilometres (1.5 miles) per second – it will be released from the tube and travel into lunar orbit, where it can be picked up by a larger cargo spacecraft for use in space or transportation to Earth. Rather than sending large payloads, a lunar mass driver will launch multiple small payloads, possibly several per second depending on its design.

These proposals have been considered for use on Earth, but the lower gravity and lack of atmosphere on the Moon makes it a much more desirable location. Creating a mass driver on Earth that could propel a payload into orbit around our planet would be very difficult. To reach and maintain low-Earth orbit, a spacecraft or payload needs to have a velocity of about 7.8 kilometres (4.8 miles) per second, and it would also have to contend with Earth's atmosphere and its strong gravitational pull. By comparison, the Moon has no atmosphere and much lower gravity, meaning a payload can more easily be accelerated to the speed required to escape the Moon.

A lunar mass driver is still very much in the concept stage. A few experiments have been carried out on the possibility of building a mass driver, but if we are to one day colonise the Moon, such a structure could be vital for the transportation of material to Earth.

"The lower gravity and lack of atmosphere on the Moon makes it a much more desirable location"

**1 Catcher**
The gravity of the Moon will reduce the speed of the payloads as they move further into space, where they will rendezvous with a catcher spacecraft positioned in lunar orbit at one of two Lagrangian points.

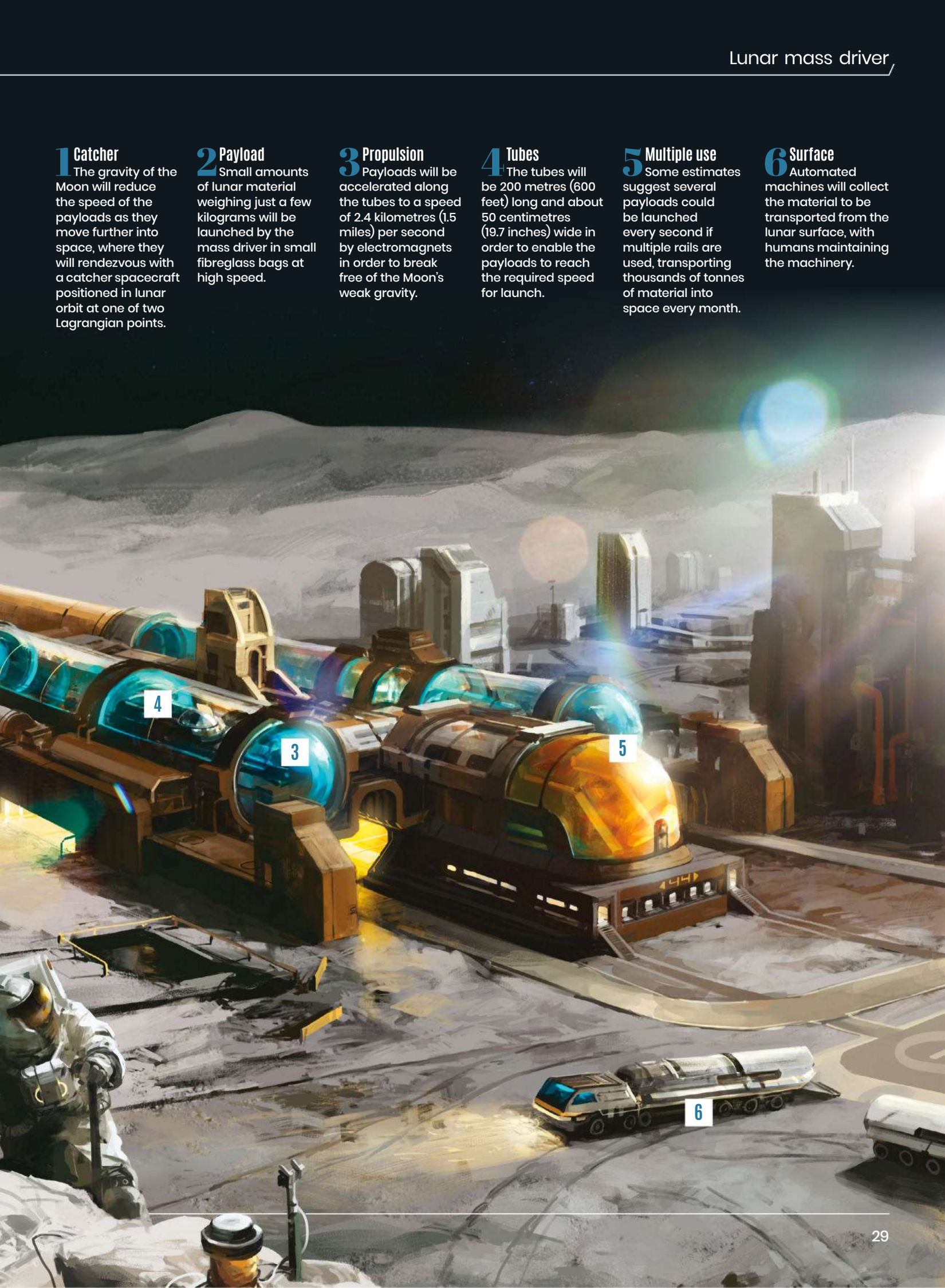
**2 Payload**
Small amounts of lunar material weighing just a few kilograms will be launched by the mass driver in small fibreglass bags at high speed.

**3 Propulsion**
Payloads will be accelerated along the tubes to a speed of 2.4 kilometres (1.5 miles) per second by electromagnets in order to break free of the Moon's weak gravity.

**4 Tubes**
The tubes will be 200 metres (600 feet) long and about 50 centimetres (19.7 inches) wide in order to enable the payloads to reach the required speed for launch.

**5 Multiple use**
Some estimates suggest several payloads could be launched every second if multiple rails are used, transporting thousands of tonnes of material into space every month.

**6 Surface**
Automated machines will collect the material to be transported from the lunar surface, with humans maintaining the machinery.



## BIO+

### Jan Davis

Davis grew up in a rocket town, and she became an astronaut who flew on rockets. The retired NASA astronaut cites her father, Benjamin Smotherman, as a large influence, and shares both of their stories in her new book: *Air Born: Two Generations in Flight*. It details her father's military service across several chapters before diving into Davis' own life. She is a veteran of three Space Shuttle missions: 1992's STS-47, 1994's STS-60 and 1997's STS-85.

## Jan Davis

# "Looking at Earth from space... it's phenomenal"

### The former NASA astronaut recounts her spaceflight career, family and more as she promotes her new book, *Air Born*

Interviewed by Elizabeth Howell

**You wrote a moving account at the beginning of *Air Born* about your father's service in World War II and being a prisoner of war (POW) for 22 months. Can you talk about how his perspective on life changed after those experiences?**

The only time he talked about being a POW was when we were going through his journal, and he was showing me the paintings and the drawings that he did. But as far as how it affected his life, I think – and he said this in some of the letters that he wrote home – he appreciated more of the little things like grass and food. For the rest of his life, he treasured white bread. It was like cake. But in terms of his outlook, he was a very positive person, a very kind and loving person, and I think he appreciated people and his family. He did make friends in the prison camp, but that was really a means of survival, to have that camaraderie.

I didn't grow up with him, but I asked my sister about how it affected him. She said he never got mad. Obviously he's motivated and a hard worker, but he knows how to deal with his emotions and he has had lots of outlets for stress or tension. He did a lot of models: aircraft models, stagecoach models, and did a lot of research on the West. He was drawing all these maps and writing about that. It's interesting, because I think that helps me, too. I do different kinds of art. I do textile arts, quilting and sewing and embroidery, things like that. When I was an astronaut corps, that's when I started quilting. But I don't know how it affected him in his relationships with people; I don't know why he and my mother divorced. I don't know why he and his second wife divorced. I don't know if he did have some flashes of the war, or anything that affected him in his relationships. But from what my sister said, he was very positive and slow to anger.

**Let's also talk about your mother, and the rest of his family as well. Do you mind talking about their experiences while he was serving?**

My mother did talk about it. She was married when she was 17 years old, and then they married the day before Pearl Harbor – that was December 1941. Then he enlisted and was gone all the time, so that was difficult for their marriage, and then he went off to war. My mother is also a very hard worker. She believes in education

Four of the crew members of STS-47 at Kennedy Space Center in 1992

© Getty

Davis enjoying a meal aboard Space Shuttle Endeavour

Davis and European Space Agency astronaut Gerhard Thiele in 2017

and living life to the fullest. From talking with her, while he was gone she continued her education. She developed a lot of skills. When I was growing up she could do so many things – so many different sports and so many different crafts. She's a lifelong learner, as I am, and I think she used that time to develop those skills and develop the experience as an athlete, doing different things. That's how she dealt with it. But my mother is the most positive person I think I've ever met. She's very encouraging, very optimistic. She always looks at the bright things in her life. That's the way she always was. I think from those few letters and also from things she said, she was very encouraging to him. I think that helped him.

As far as the rest of the family, I don't really know them that well, but he had a very supportive family. That's why he moved back to Texas, so that his family could help him raise his three children after his divorce. He was a big family man. That encouragement and support from my mother and his family was so important for not only his physical survival, but his emotional survival through all that trauma that he went through.

**What influenced your interest in science, space and related fields?**

My stepfather and mother left Florida when I was about ten years old. I moved to Nashville. I talked in the book about how my stepfather was a psychologist, and he had a friend who opened up a practice here in Huntsville, so we all moved to Huntsville. My parents wanted to get out of this little town where we lived in Florida for more opportunity for me, and for them as well. We moved here in 1963. As you know, we started flying in space in 1961. And we just had the challenge from Kennedy to go to the Moon before the end of the 1960s.

Huntsville was one of those places that was booming. I mean, we couldn't even find a house. It was growing so fast, and it was so exciting to be there at that time. They were testing the engines, and the whole town would shake and vibrate, and break windows. It was like, "Wow, we're going to the Moon!" Also, going to school with the German teams' kids, and other engineers' kids, greatly influenced me and my interest in the space program. It was all around me. Liking maths and science drew me to engineering. I never dreamed I would work in the space program, but the people supporting the space program had a big influence on my career selection, and I had great teachers. And we had lots of talks about people in the space program – things that they were using, their models and how things worked. It was a great place to grow up, especially as it relates to the space program.

**Can you talk about joining NASA?**

I was fortunate enough to be hired as an engineer in 1979, before the Space Shuttle flew in 1981. They were trying to ramp up people to work on not only the Shuttle, but also things that flew on the Shuttle, which is why I worked on the Hubble Space Telescope, which was amazing. They had just selected the first group of astronauts to fly in the Space Shuttle in 1978: 35 astronauts, of which there were six women. For the first time, the astronauts were not only military test pilots, but also engineers, doctors, scientists – people who would work on the Space Shuttle as mission specialists. That opened everyone's eyes to the opportunities to become an astronaut. Before that time, the military test pilots were all male. Now we had an opportunity for women, other civilians and other professional disciplines.

© Getty

I didn't really think about it at that point, when I started working for NASA, but then when the next class was selected in 1980 it had two women. Someone said to me, "Why don't you think about that?" And to me, it seemed really far-fetched. I'm like, "Wow, me. How's that going to happen?" But I looked into it. It turns out about that time I was already in graduate school. My background was what they were looking for, and I knew that I needed to keep going to school to get my graduate degrees.

I also had the opportunity to swim with astronauts in the Neutral Buoyancy Space Simulator in Huntsville, at Marshall Space Flight Center. They were training astronauts on Hubble there. Since I was working on Hubble, I was allowed to swim as a diver with those astronauts who are doing their extravehicular activity training. I asked them what else can I do to improve my chances, and I was doing things that they recommended: take flying lessons, keep going to school and keep working your best at your job

NASA had this fantastic program – really the government, not just NASA – where they would pay you to go to school. They not only paid your tuition, but they paid your salary for a year of full-time study, which for me turned out to be a year and a half. That's how I was able to get my PhD. When I got the call to be interviewed the first time [that I applied as an astronaut], that was a real motivator. They had 5,000 applicants and they only interviewed 128. Being one of those 128, I was like, "Wow, maybe this is possible. Maybe there's a chance I can do this."

I wasn't selected that year, in 1984, but it made me buckle down and finish that PhD and then do other things I thought might help even more. In the meantime, in 1986, the Challenger [Space Shuttle disaster that killed seven astronauts] happened. It put a halt to everything, including my hopes of being an astronaut. I thought that wasn't going to happen, because the solid rocket boosters that caused the accident were managed by Marshall Space Flight Center. I didn't think there was any chance that anyone at Marshall would ever be selected.

But I was put in charge of a part of the redesign; not the O-ring part, but a different part of the boosters, for return to flight. I concentrated on that, thinking that I didn't have a chance of being selected, so I might as well focus on that. That's what I did. But then I got the call in 1987 to be interviewed, and that's the year I was selected.

**Let's talk about your missions. What do you think people should take away from those adventures?**
Looking at Earth from space... it's phenomenal. Just magnificent views that you can see with your eyes, which cameras – whether video or still photography – can't capture. That was my favourite thing to do. But that was not our job. We had very, very busy missions and lots of science and other things. I didn't get that much chance to look out the window, but when I did, I think my perspective on Earth changed in a couple of ways.

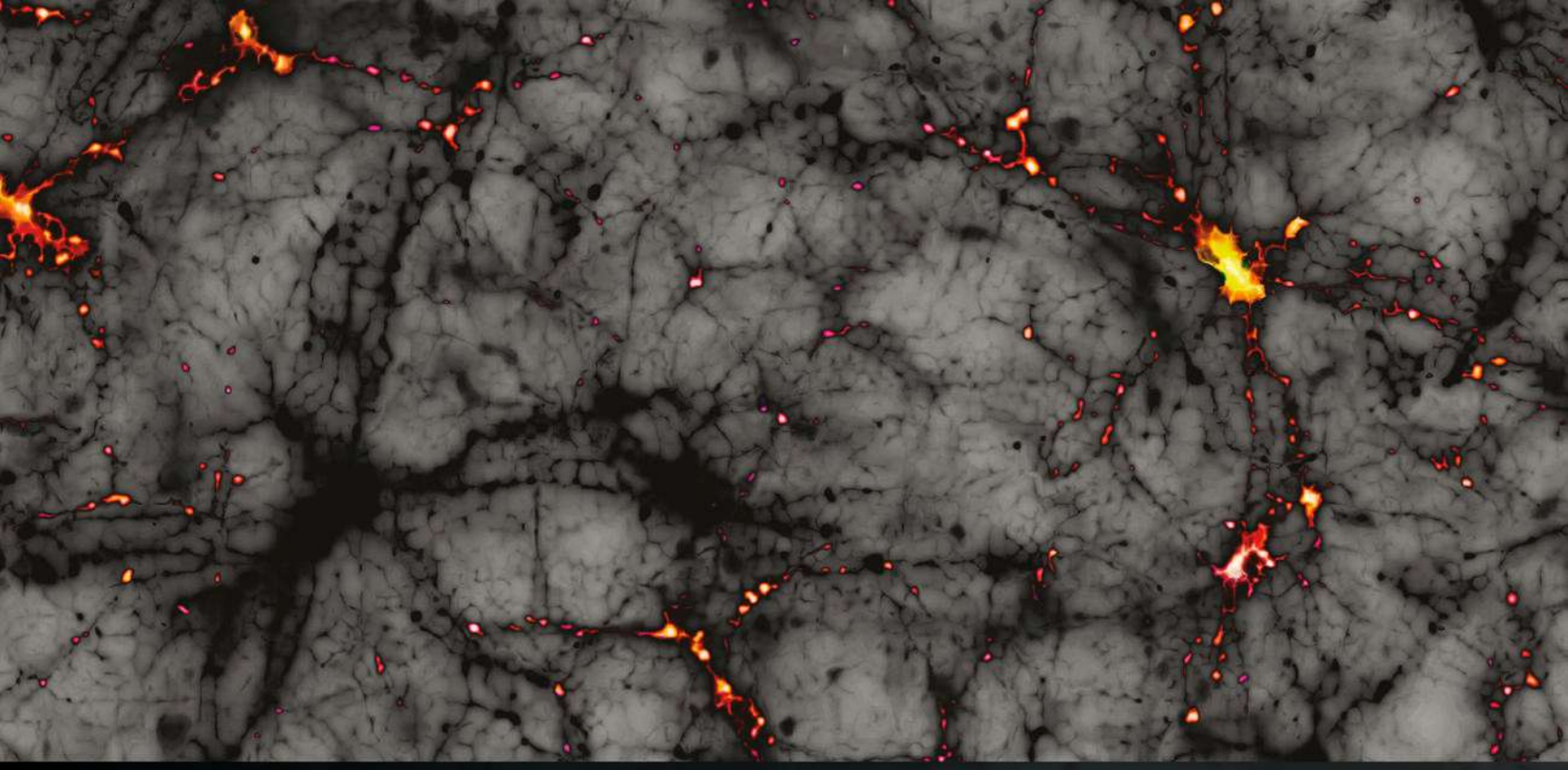
The layer of that atmosphere is so thin. It's like the peel of an orange. So I saw and realised how fragile our atmosphere and our environment really is. You could see areas affected by people. You can also see where dust or smoke or something would travel from one continent, across the ocean, to another continent. So what happens in your local area, and what you do to the atmosphere, affects somebody somewhere else on Earth.

The second was similar, but relates to the people on Earth. When you go around the Earth in an hour and a half, you see these countries go by. You don't see borders or different countries. You see one place. We're all neighbours. We're all inhabitants of this Earth. Gosh, if people could see that perspective from space, maybe we wouldn't have wars or violence or people hurting each other. We need to take care of our home, but we also need to take care of each other.

**Was there anything else that you wanted to emphasise from the book, from your career or anything else?**
I wrote the book because I didn't have access to my father's POW logbook until my sister sent it to me in April of 2020. I looked at what little I knew about his story and his career and I said, "Wow, I need to tell the story. I need to publish his beautiful paintings and tell his story." So I decided to write a book about him. Initially, I wasn't going to write about myself, necessarily. But as I did more research into his flying career and his training as a pilot on the B-17, I realised there were a lot of parallels between what he went through and what I went through. Both in our training, but also in our camaraderie, with people we flew with. How do we each deal with that? How do we prepare our families for that?

Writing and doing the research was a real discovery for me, filling in the gaps of my life. I didn't know that much about him, and for the rest of his family, they didn't know a lot of the things that I found out. It was a healing process. I'm learning about how his life intertwined with mine. That's why I wrote the book, and it generated a whole lot more for me personally than I ever would have realised.

The crew of STS-47 – Davis' first flight – posing for a group shot in microgravity



An illustration of what dark matter might look like

FOCUS ON

# HYPOTHETICAL 'DARK PHOTONS' COULD SHINE A LIGHT ON DARK MATTER

**These massive particles could serve as the connection between dark matter and the everyday matter that comprises stars, planets and us**

Reported by Robert Lea

A theorised massive particle called a dark photon could help shine a light on the secrets of dark matter, the universe's most mysterious substance. Dark matter is currently a huge problem for physicists because, despite comprising as much as 85 per cent of the stuff in our universe, it remains effectively invisible. This is because dark matter doesn't interact with light like the everyday matter that makes up stars, planets and even our bodies. Dark matter can only be inferred through its interactions with gravity and its influence on everyday matter.

This strange lack of interplay with light, or electromagnetic radiation, also reveals that dark matter isn't made up of atoms that are composed of particles like protons and neutrons. That fact has spurred scientists to search for particles that could comprise dark matter; these particles would have to outnumber the particles which make up standard matter, also known as baryons, by a ratio of five to one.

While dark photons aren't usually suggested as a candidate for dark matter itself, they could be force carriers, just like 'ordinary' photons. More specifically, these particles of light carry the electromagnetic force. And if they do carry some sort of dark electromagnetic force, per se, dark photons could act as a go-between for dark matter and ordinary baryonic matter. That bridge could happen via an interaction known as 'kinetic mixing' with standard photons.

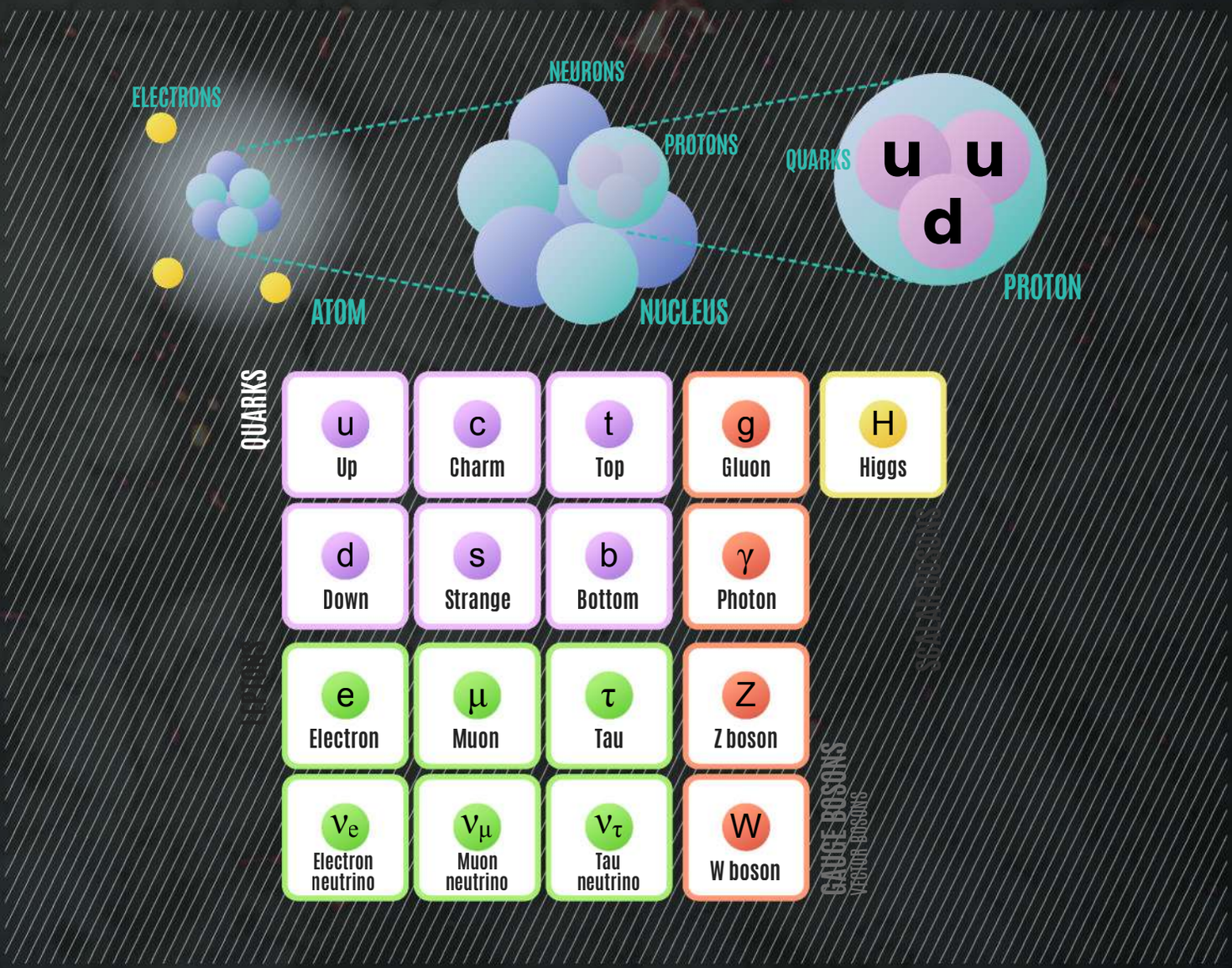
Ultimately, understanding this interface could in turn help us understand dark matter. "The existence of dark matter has been firmly established from its gravitational interactions, yet its precise nature continues to elude us, despite the best efforts of physicists around the world," University of Adelaide professor of physics Anthony Thomas said. Thomas was part of a team that looked at how dark photons could affect collisions between particles at incredibly high energies by kinetically mixing with standard photons. Byproducts created by these collisions can

give scientists a good picture of the universe at scales smaller than an atom, as well as what physical laws are at play on these levels. "In our latest study, we examine the potential effects a dark photon could have on the complete set of experimental results from the deep inelastic scattering process," Thomas said.

Inelastic scattering results from billiard ball-like collisions that happen when particles bump into one another, changing the kinetic energy of the system. These inelastic collisions, first observed in 1922 in the form of X-rays scattered by a thin foil of graphite, can help scientists peer inside baryonic matter and the baryons themselves via the effect they have on other particles like electrons, muons and neutrinos.

The team employed a state-of-the-art framework used to measure the distribution of these other particles to see how the particles that comprise protons and neutrons – quarks, antiquarks and gluons – have momentum distributed among them after a collision. The framework is called the Jefferson Lab Angular Momentum (JAM) parton distribution function global analysis framework. However, the researchers modified the theory underlying this framework to allow for the existence of dark photons. This analysis suggested that the dark photon hypothesis was preferred over one that follows the Standard Model of particle physics, which neglects dark photons. And it did so, Thomas believes, to a significance that would be high enough in other circumstances to act as evidence for the discovery of a new particle.

Though the work doesn't actually prove the existence of the dark photon, it surely narrows down the parameters at which this particle could exist and builds towards an understanding of how strongly it would kinetically interact with standard photons. For future research into the existence of dark photons, the team suggests improving statistical analyses of all observables in the system being examined.

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FOCUS ON

# 3D SIMULATIONS SUGGEST THAT SUPERMASSIVE BLACK HOLES EAT MORE QUICKLY THAN EXPECTED

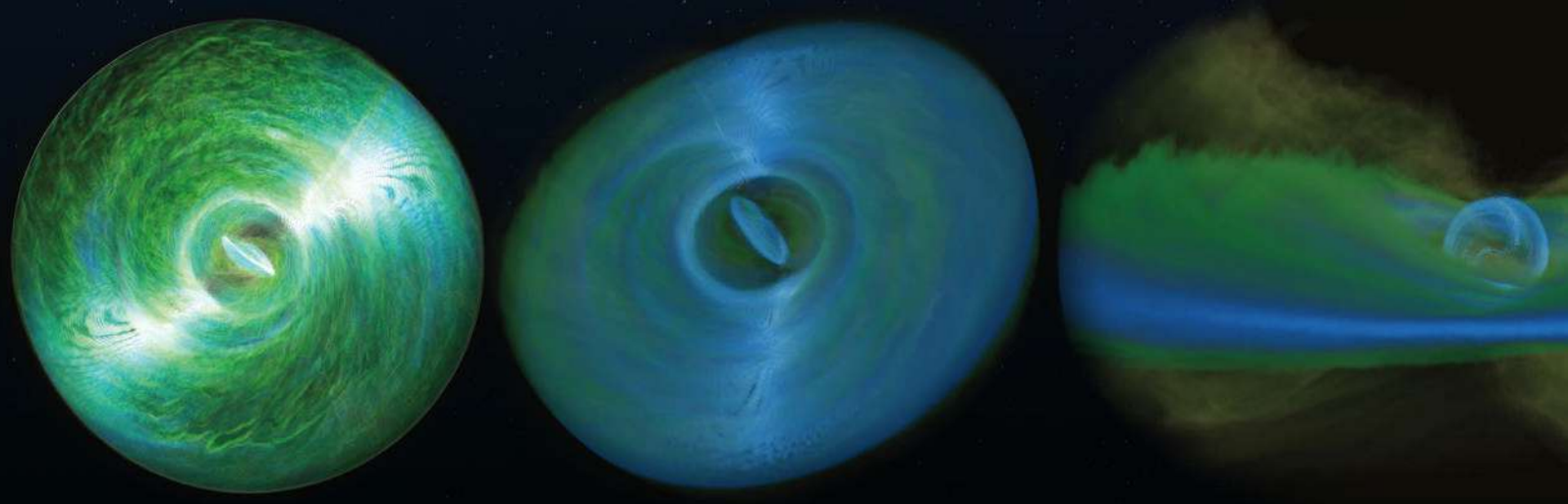
## Black holes at the hearts of galaxies have an unexpected delivery service that helps them feed over months rather than hundreds of years

Reported by Robert Lea

Supermassive black holes may have a completely unexpected cosmic delivery service supplying them with gas and dust to feast on. This could result in the cosmic titans feeding much faster than scientists had expected, gorging themselves over a period of months rather than hundreds or even thousands of years. Supermassive black holes with masses of millions or even billions of times that of the Sun are believed to dwell at the hearts of most galaxies, and when they're surrounded by vast plates of gas and dust called accretion discs, they power quasars.

These new findings about black hole feeding rates could help shed light on how these supermassive voids gobble up surrounding material and how that process influences the evolution of galaxies. The research is the result of high-resolution 3D simulations performed by a team of scientists who set out to understand black hole dynamics and ended up capturing a surprisingly quick feeding rate of these elusive phenomena. This increased feeding rate may be supported by real-world observations of quasars as well, some of which brighten and fade with a timescale of months. "How gas gets to a black hole to feed it is the central question in accretion-disc physics," Nick Kaaz, team leader and an astronomer at Northwestern University, said. "If you know how that happens, it will tell you how long the disc lasts, how bright it is and what the light should look like when we observe it with telescopes."

Supermassive black holes are so massive that when they spin they drag the very fabric of space-time along with them – a phenomenon called frame dragging or the Lense-Thirring effect. 3D simulations performed using the Summit supercomputer at Oak Ridge National



Laboratory showed that this twisting of space rips up accretion discs and causes them to split into inner and outer 'subdiscs'. Supermassive black holes treat the inner disc as an appetiser, in a way, because they start their dinner by devouring gas and dust found there first. As this is happening, matter from the outer disc filters in, eventually filling in gaps left behind by the black hole devouring the inner disc. This filled-in disc then becomes the main course, allowing the feeding process to start all over again.

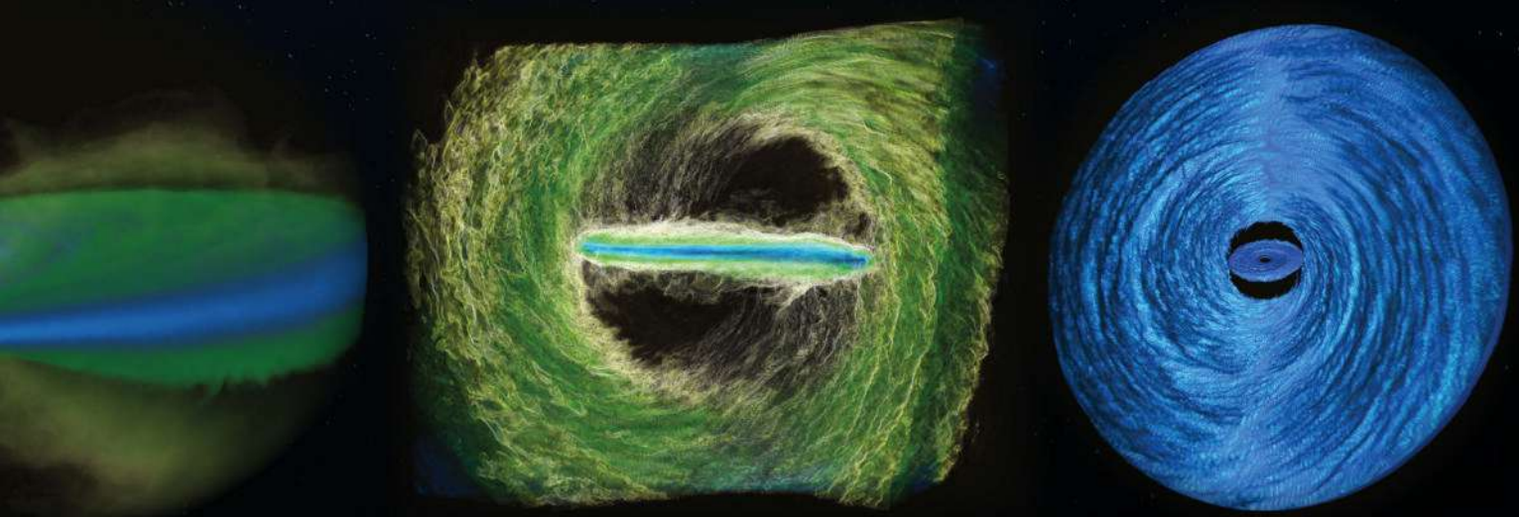
The black hole's entire cosmic dining experience of eating, refilling, then eating again can proceed over a matter of mere months, the team's simulations suggested, which is radically more rapid than previously calculated timescales. This may ultimately explain why some quasars flash quickly and then disappear. "Classical accretion disc theory predicts that the disc evolves slowly," Kaaz said. "But some quasars – which result from black holes eating gas from their accretion discs – appear to drastically change over timescales of months to years. This variation is so drastic."

Kaaz, who is also a member of the Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) at Northwestern, added that from the simulations it looks like the inner part of the disc – where most of the light of a quasar comes from – gets destroyed and then replenished. "Classical accretion disc theory cannot explain this drastic variation," he said. "But the phenomena we see in our simulations potentially could explain this. The quick brightening and dimming are consistent with the inner regions of the disc being destroyed."

Some scientists have suggested that accretion discs surrounding supermassive black holes are quite well-ordered, despite the violent conditions they experience, thanks to the gravitational influence of the supermassive black holes sitting at their centres. Due to this influence, gas and dust in accretion discs orbit black holes while staying in the same plane and spinning in the same direction as the voids, with gas very gradually falling to the outer boundary of the black hole, known as the event horizon. "For decades, people made a very big assumption that accretion discs were aligned with the black hole's rotation," Kaaz said. "But the gas that feeds these black holes doesn't necessarily know which way the black hole is rotating, so why would they automatically be aligned? Changing the alignment drastically changes the picture."

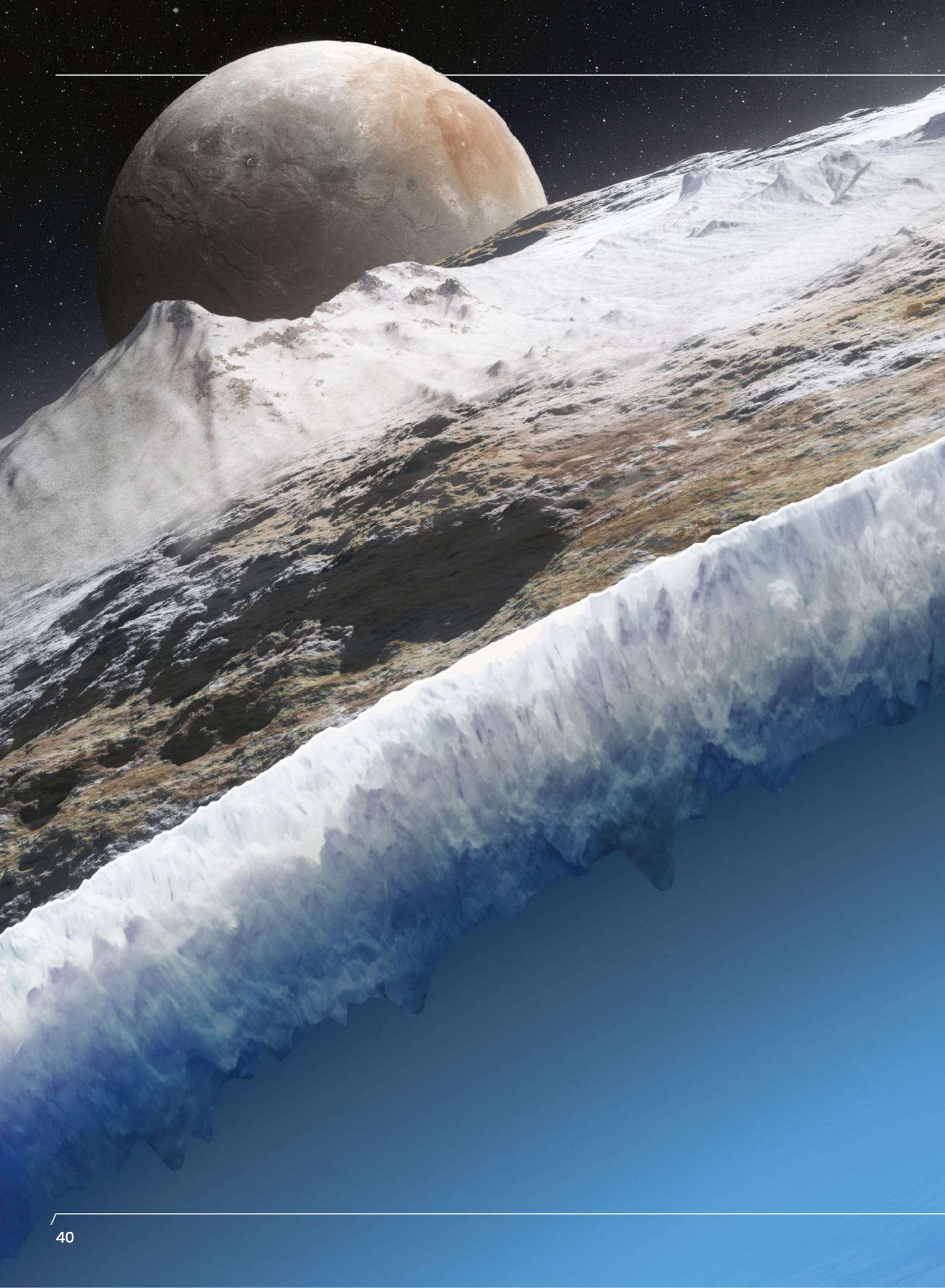
This newly presented picture indicates a more messy and turbulent environment around a feeding supermassive black hole. At the heart of this is the Lense-Thirring effect, which gets stronger as you move closer to the central black hole, causing accretion discs to wobble and the innermost region to spin faster. This is comparable to a spinning top, which begins to wobble as it slows down, but the wobble of the inner accretion disc is more extreme than that of the outer disc. This warps the entire disc system and causes gas from different regions to smash into each other, creating bright shocks and driving material ever closer to the supermassive black hole itself. Eventually, the wobbling effect becomes so strong that the accretion disc splits. The resultant inner and outer discs evolve separately and develop different wobbles. At that point, the entire accretion disc is more like the rings of a gyroscope rather than a spinning plate. "When the inner disc tears off, it will precess independently," Kaaz said. "It precesses faster because it's closer to the black hole, and because it's small, so it's easier to move."

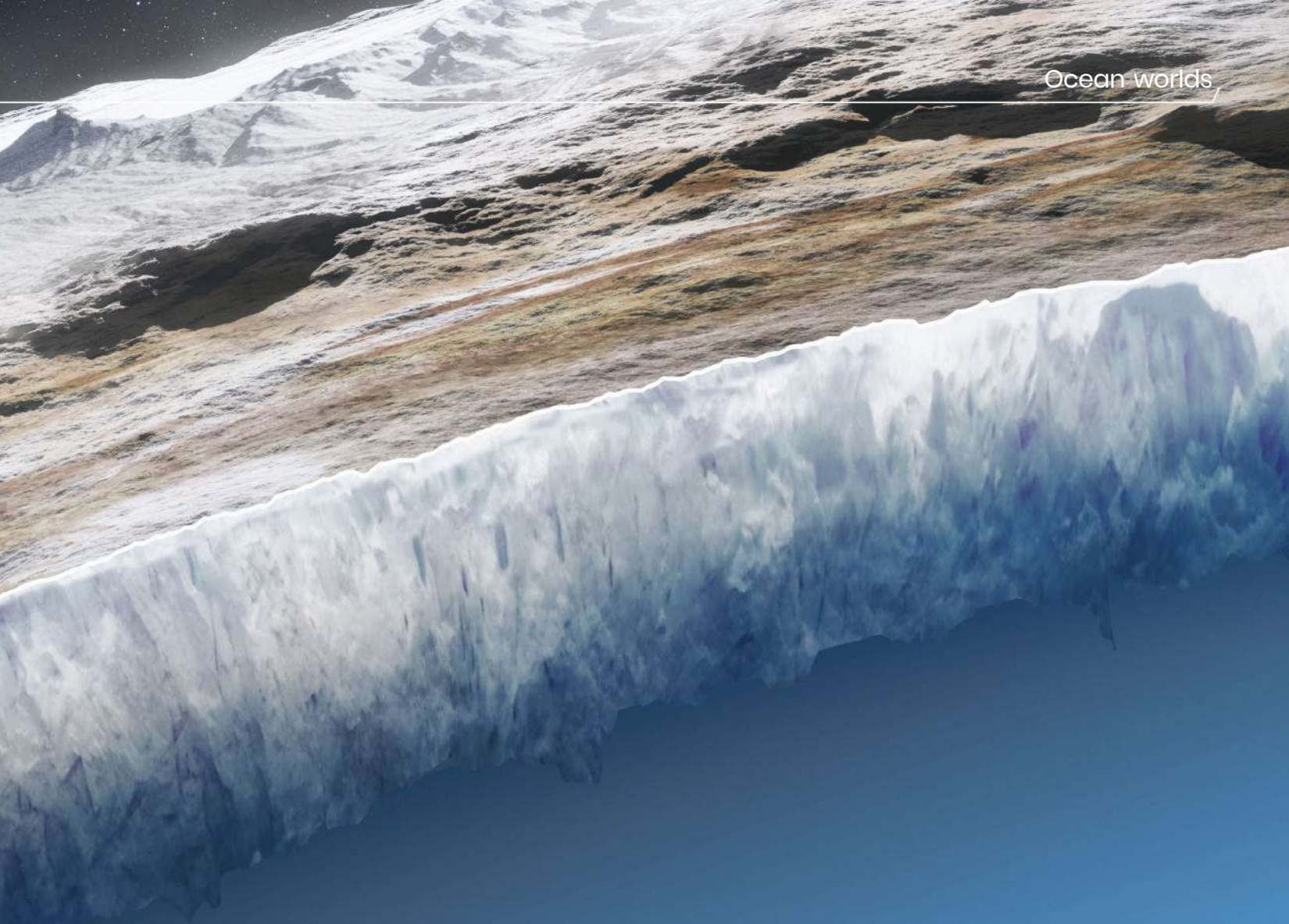
Simulations created by the team indicated that the frenzied feeding of supermassive black holes starts at the break, or 'tearing region', between the inner and outer discs. Furthermore, this happens as friction attempts to unify the discs while the Lense-Thirring effect further wrenches them apart. "There is competition between the rotation of the black hole and the friction and pressure inside the disc," Kaaz said. "The tearing region is where the black hole wins. The inner and outer discs collide into each other. The outer disc shaves off layers of the inner disc, pushing it inwards." Because the discs are oriented at different angles, the outer disc pours matter onto the inner disc, which pushes the inner disc closer to the black hole, speeding up the rate at which it's swallowed by the black hole. As this happens, the immense gravity of the black hole pulls in the outer disc, forcing it to take the place of the inner disc.



Screenshots of a simulation showing a new way in which supermassive black holes feast on their surrounding discs of gas and dust

© Getty / A Tchekhovskoy, Nick Kaaz, Northwestern University



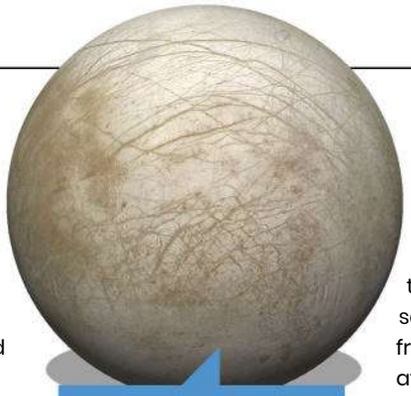


# THE SOLAR SYSTEM'S OCEAN WORLDS

**Pack your swimming costume – the Solar System is much wetter than you think**

Written by Luis Villazon

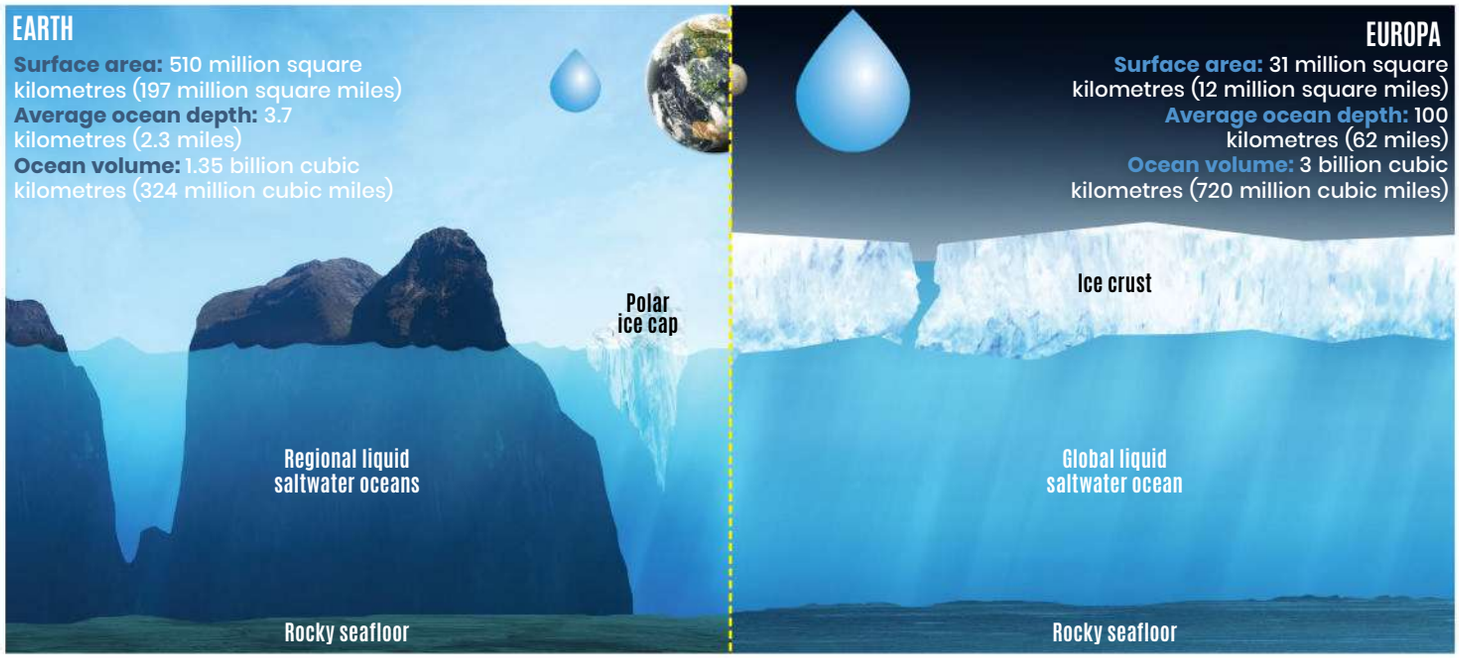
# EUROPA



**SIZE:** 25 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 4.9 to 5.4 astronomical units
**BIOLOGICAL POTENTIAL:** Possible
**TYPE OF OCEAN:** Active
**SIZE OF OCEAN:** Twice as big as Earth's

Europa is Jupiter's fourth-largest moon and the smoothest of all the celestial bodies. There are almost no craters, and despite a dense network of cracks and ridges covering this moon, none are higher or deeper than a few hundred metres. This suggests that Europa's surface is geologically young and possibly floating on a liquid mantle. The Hubble Space Telescope has also spotted plumes of water vapour spewing 200 kilometres (124 miles) into the air from the south pole. This lends weight to the idea that Europa has a subsurface saltwater ocean covered by a layer of ice that may be just a few kilometres thick in places.

Tidal flexing and friction from gravitational interactions with Jupiter generate enough heat to keep the interior ocean liquid, but because it's so far from the Sun, the surface remains frozen. Europa also has a very thin oxygen atmosphere, generated when radiation splits water molecules in the surface ice. A tiny fraction of this could become trapped within the ice and would eventually be carried down to the subsurface ocean by tectonic subduction. A 2007 study at Stanford University in California calculated that it was possible for the oxygen levels in Europa's ocean to equal that of Earth's own deep seas, further bolstering Europa's chances of harbouring life.


EARTH
Surface area: 510 million square kilometres (197 million square miles)
Average ocean depth: 3.7 kilometres (2.3 miles)
Ocean volume: 1.35 billion cubic kilometres (324 million cubic miles)
EUROPA
Surface area: 31 million square kilometres (12 million square miles)
Average ocean depth: 100 kilometres (62 miles)
Ocean volume: 3 billion cubic kilometres (720 million cubic miles)
Ice crust
Polar ice cap
Regional liquid saltwater oceans
Global liquid saltwater ocean
Rocky seafloor
Rocky seafloor

**SIZE:** 41 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 4.9 to 5.4 astronomical units
**BIOLOGICAL POTENTIAL:** Unknown
**TYPE OF OCEAN:** Trapped
**SIZE OF OCEAN:** One to six times Earth's

# GANYMEDE

Ganymede, Jupiter's largest moon, is eight per cent larger than Mercury but only half its mass. Such a low density suggests that it should be made of equal parts rock and water. In the 1990s, the Galileo spacecraft found that Ganymede has its own magnetic field, which means that it must have a molten iron core. The heat from this core would be enough to melt ice and create an enormous subterranean ocean. This ocean could be a 100-kilometre (62-mile) thick layer sandwiched between an icy crust on the surface and another layer of ice below, kept solid by the enormous pressures within the moon. Other models have suggested that there might be several different oceans, arranged in concentric rings like an onion, with different phases of solid ice separating them. Ganymede's ocean is trapped a long way underground, so we don't see any water plumes spewing at the surface like on other moons, but there are other observations that provide direct evidence of its ocean.

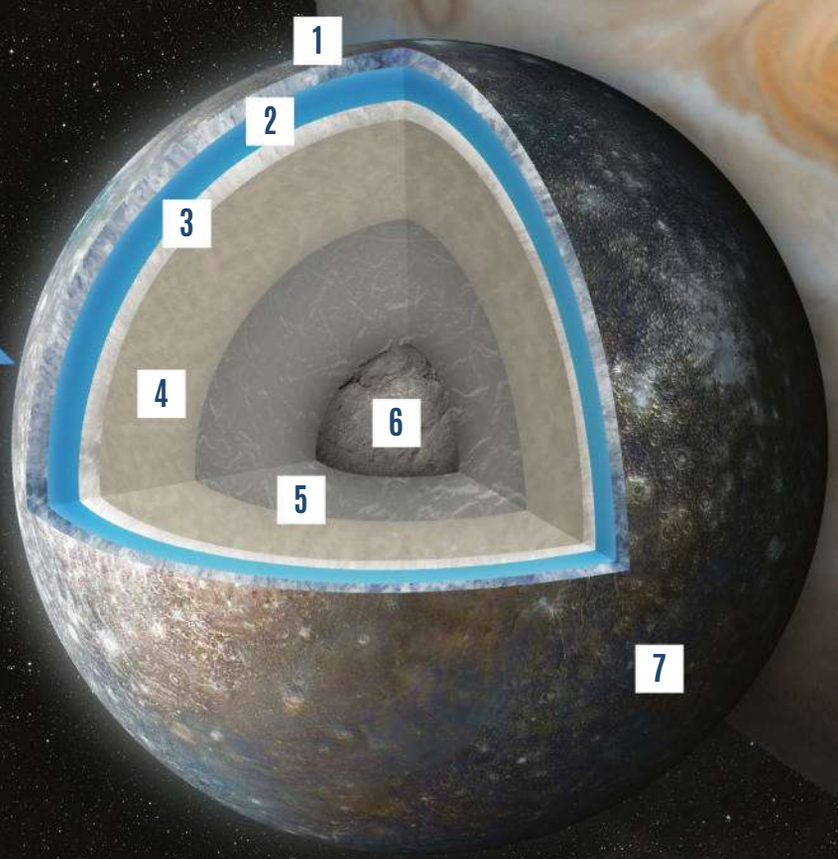
As Ganymede completes its orbit around Jupiter, its giant parent planet's massive magnetic field creates polar aurorae in Ganymede's thin atmosphere. But the salt in Ganymede's seawater makes it electrically conductive, and this creates magnetic drag, which reduces the amount that the aurorae oscillate around Ganymede's poles.

# CALLISTO

Callisto is Jupiter's second-largest moon. It's almost as large as Mercury, but one-third as massive, which means that it is about 50 per cent water. The strange thing about Callisto is that the surface is completely saturated with craters, with no breaks or smooth plains caused by geological processes below. Not only is Callisto geologically dead today, it probably always has been. Gravity measurements from the Galileo spacecraft show that the internal structure hasn't fully separated out into a rock core with a pure water or ice mantle. This means that the ice never fully melted during Callisto's formation.

Despite this, we know that Callisto does have a liquid ocean near the surface. Measurements of its interactions with Jupiter's magnetic field show that it must have an electrically conducting layer at least ten kilometres (6.2 miles) thick just below the surface. Callisto orbits too far away from Jupiter to receive any significant tidal heating, so for this ocean to remain liquid, it must contain something besides water to act as antifreeze – A five per cent mixture of ammonia would be enough. Callisto lies outside Jupiter's main radiation belt and has ample water ice on the surface, which makes it a good candidate for a future human base. But conditions within its underground ocean are much less hospitable. As well as being very cold, the liquid water is sandwiched between two layers of ice, so there's no influx of minerals and only very slow heat transfer from the core.

**SIZE:** 38 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 4.9 to 5.4 astronomical units
**BIOLOGICAL POTENTIAL:** Unlikely
**TYPE OF OCEAN:** Trapped
**OCEAN VOLUME:** Half of Earth's




**1 Hexagonal ice**
Callisto's crust is made of ice with the same crystalline structure as the ice common on Earth.

**2 Saltwater ocean**
Just below the crust, temperatures may be high enough for a saltwater ocean at least ten kilometres (6.2 miles) deep.

**3 Monoclinic ice**
Also known as 'ice V', this complex crystalline form of water only forms at a very narrow pressure range.

**4 Rock and tetragonal ice**
At deeper levels the rock hasn't completely separated from the ice, which now exists in the 'ice VI' or tetragonal phase.

**5 Rock and cubic ice**
At pressures of over 30,000 atmospheres, the ice is squeezed into the more stable 'ice VII' phase.

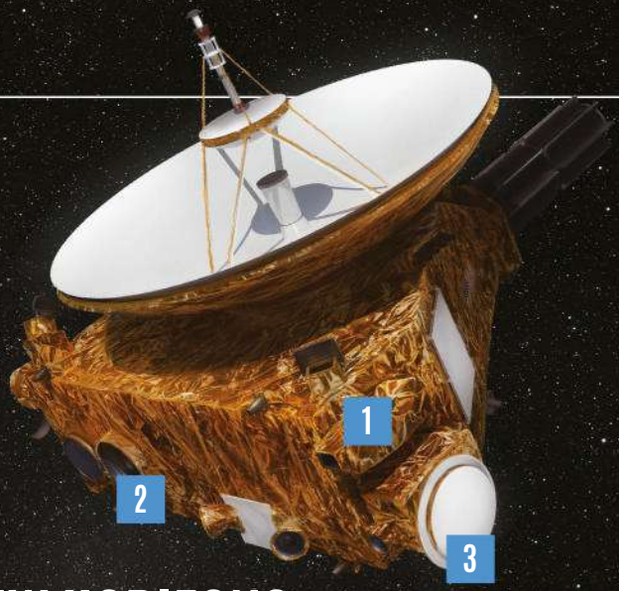
**6 Core**
Some 1,800 kilometres (1,118 miles) under the surface is a solid rock and metal core with no water at all.

**7 Craters**
The only surface features are dense impact craters, indicating that Callisto is geologically inert.

# PLUTO

Pluto is too small to have retained enough heat to keep its core molten. Radioactive heating under the surface only provides one-fiftieth of the energy that radiates upwards on Earth. But that's still enough to melt the lighter elements and allow the heavier silicate minerals to sink. The result is a rocky core 1,700 kilometres (1,056 miles) across, surrounded by a layer of water and ice 100 to 180 kilometres (62 to 112 miles) thick. Pluto's surface is so cold that it is blanketed by snow made of solid nitrogen, methane and carbon monoxide, but spectrometry data from New Horizons suggests the 'bedrock' is water ice.

Deep in the mantle, the heat from the core could be keeping this as a mixture of slush and water. The heart-shaped Tombaugh Regio is in an area absent of craters, suggesting the surface is geologically active. The western half, Sputnik Planitia, lies close to Pluto's equator, keeping it at a stable temperature. For millions of years the nitrogen ice on the surface has been slowly circulating on convection currents driven by the subterranean ocean. This provides a clue that the water inside Pluto behaves like the molten magma in Earth's mantle.




## NEW HORIZONS

**Launched in 2006, the NASA spacecraft made some surprising discoveries at Pluto**

**1 Alice**
An imaging spectrometer that scanned Pluto's atmosphere in wavelengths extending into the extreme and far-ultraviolet spectrum.

**2 LORRI**
The Long Range Reconnaissance Imager is a digital camera and telescope that spotted surface features for mapping Pluto.

**3 Ralph**
Ralph is a high-resolution visible and infrared imager and spectrometer that was used to provide colour and create thermal maps.

### Surface water
Infrared spectroscopy revealed small patches of water ice. When this data is superimposed on the photos of visible terrain from Ralph, we can see the ice appears in impact craters and deep canyons.



### Crust made of ice
Most surface water ice isn't visible as it's covered with a thin layer of methane and carbon monoxide. By subtracting these compounds, scientists have found that much of Pluto's bedrock is water ice.

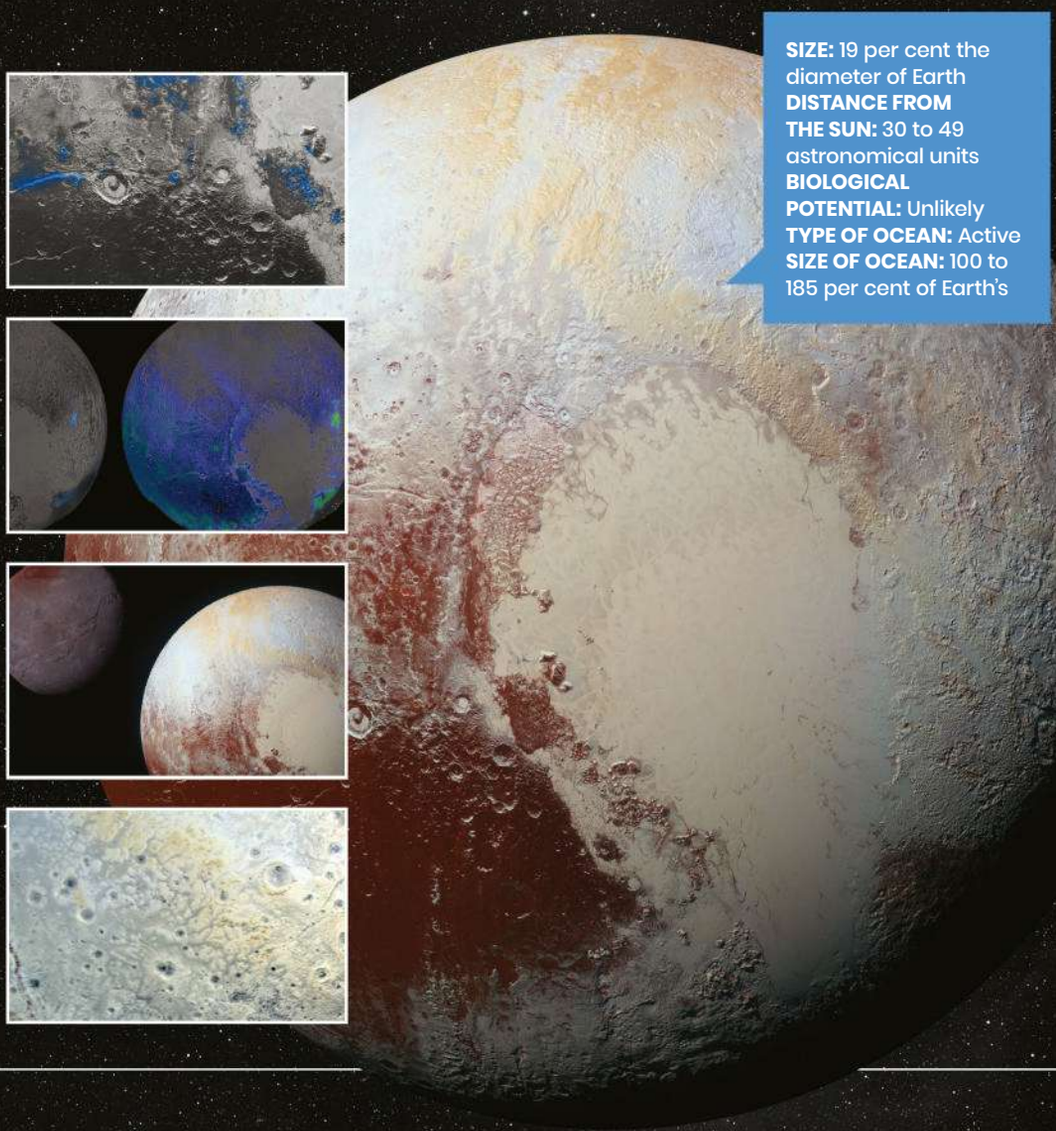


### Subterranean ocean
Pluto's famous heart-shaped region could be explained by an impact crater that thinned the crust and allowed the denser liquid ocean to move closer to the surface.



### Cracks and fissures
If Pluto's ocean had ever frozen solid, the pressure of its own gravity would have compressed it into a more compact form of water. Photos show the crust is cracking apart as the still-liquid ocean slowly freezes.





**SIZE:** 19 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 30 to 49 astronomical units
**BIOLOGICAL POTENTIAL:** Unlikely
**TYPE OF OCEAN:** Active
**SIZE OF OCEAN:** 100 to 185 per cent of Earth's

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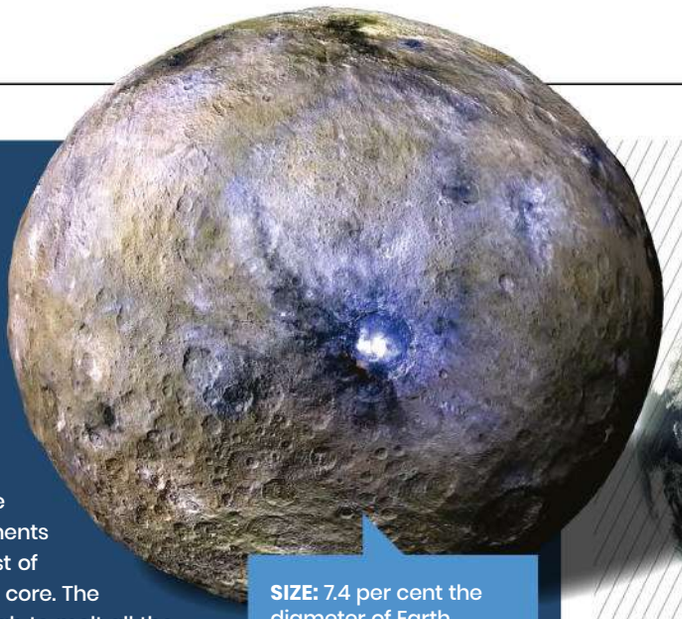
# CERES



Ceres is the largest object in the asteroid belt between Mars and Jupiter and the only dwarf planet in the inner Solar System. It was originally formed as a mixture of porous rock with about ten per cent ice. Early in Ceres' formation, heating from the radioactive decay of heavier elements melted the ice, which caused most of the rock to sink down towards the core. The heating wouldn't have been enough to melt all the way to the surface – the outer ten kilometres (6.2 miles) or so has stayed frozen – but as the subterranean ocean warmed, it expanded and forced cracks in the surface. Over billions of years, convection currents have carried away the heat from the core and allowed the interior to mostly freeze solid again, but Ceres still seems to have some liquid water beneath the surface.

The Herschel Space Telescope observed plumes ejecting water vapour into space at a rate of six kilograms per second. The total amount of water in Ceres' icy mantle is more than all the fresh water on Earth, but it's difficult to tell how much of this is liquid. Since Ceres doesn't have a large gas giant parent to generate significant tidal heating, all of its core energy comes from radioactive decay, and the proportion of radioactive isotopes in the core is currently unknown.

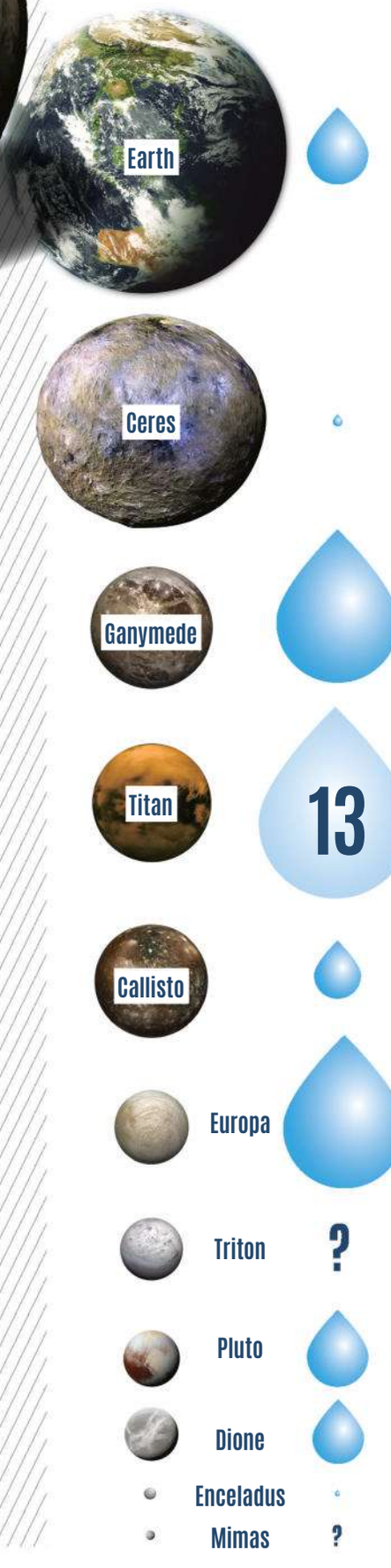
**SIZE:** 7.4 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 2 to 3 astronomical units
**BIOLOGICAL POTENTIAL:** Unlikely
**TYPE OF OCEAN:** Trapped
**SIZE OF OCEAN:** Under three per cent of Earth's

**SIZE:** 21 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 30 astronomical units
**BIOLOGICAL POTENTIAL:** Unlikely
**TYPE OF OCEAN:** Active
**SIZE OF OCEAN:** Unknown

# TRITON

Triton is the largest moon of Neptune. It's slightly larger than Pluto and has almost the same composition. It's likely they both formed in the Kuiper Belt and later fell deeper into the Solar System as a result of the gravitational pull of Neptune and Uranus. Neptune gravitationally captured Triton, but the moon has a retrograde orbit – it orbits in the opposite direction to Neptune's own spin. When it was first captured, its initial orbit was very eccentric; this generated a lot of tidal heating as Triton flexed and relaxed with each orbit. This heat was enough to melt the interior and cause it to separate into a dense core with a liquid-water mantle and a solid crust of water and nitrogen ice. Once the crust was isolated from the core by this liquid layer, it was free to flex, which increased the effects of tidal heating and helped stop the ocean refreezing as Triton's orbit decayed. Eventually, after a billion years, Triton's orbit became circular enough to lose most of its tidal heating, but it still receives energy from the core's radioactive elements. Computer models show it would only take a small amount of dissolved impurities in the water, such as ammonia, to lower the freezing point and keep Triton's ocean liquid.

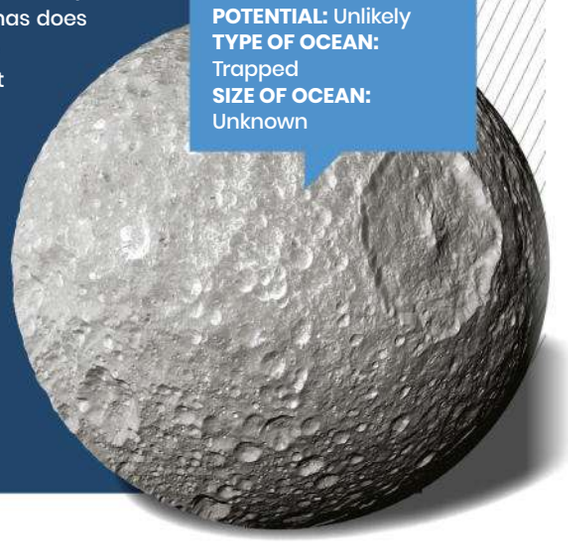
## SOLAR SYSTEM OCEAN SIZES



# MIMAS

Saturn's moon Mimas may mostly be composed of water ice with a smattering of rock – like a gritty snowball. It's only just large enough to be pulled into a rounded shape by its own gravity. Unlike its slightly larger cousin Enceladus, there are no visible plumes or geysers, and its surface is very heavily cratered, which suggests that the crust has remained frozen for billions of years and doesn't get recycled into the moon's interior. This is odd because Mimas orbits closer to Saturn and in a more eccentric orbit, so it should receive much more tidal heating. However, an analysis of images from Cassini found that Mimas does wobble slightly in its orbit, and there are only two theoretical models that explain this. Either Mimas has a dense, elongated core that throws it off balance or it has a liquid ocean under the crust that lets the core move around inside. If Mimas does have a liquid ocean, it must be capped with a very thick, strong crust to prevent any cracking or geysers. But that doesn't fit in with our observations of other moons and dwarf planets around the Solar System.

**SIZE:** Three per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 9 to 10 astronomical units
**BIOLOGICAL POTENTIAL:** Unlikely
**TYPE OF OCEAN:** Trapped
**SIZE OF OCEAN:** Unknown



# DIONE

Saturn's moon Dione could be 50 per cent water with a heavier rocky core. Dione is twice as large as Enceladus but has a much less eccentric orbit, so it receives less heat from tidal stresses. This gives it a much thicker frozen crust, some 100 kilometres (62 miles) thick. By analysing variations in the trajectory of Cassini as it made several flybys of Dione, scientists concluded that this crust could be floating on a liquid ocean 35 to 95 kilometres (22 to 59 miles) deep. Dione is heavily cratered and doesn't have geysers, but one hemisphere is covered with huge cliffs of ice that are hundreds of metres high and hundreds of kilometres long. These are probably scars left over from early in Dione's life, when the surface was still geologically active. Its ocean may be liquid all the way down to the bedrock, rather than sandwiched between two layers of ice.

**SIZE:** Nine per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 9 to 10 astronomical units
**BIOLOGICAL POTENTIAL:** Possible
**TYPE OF OCEAN:** Trapped
**SIZE OF OCEAN:** 0 to 118 per cent of Earth's

# ENCELADUS

In 2005, NASA's Cassini probe observed plumes of water vapour erupting near the south pole of Saturn's moon Enceladus. Because the gravity on Enceladus is only one per cent of Earth's, the ice crystals are easily flung into orbit, and we now know they're responsible for most of the material in Saturn's E ring. Enceladus has a rocky core around 370 kilometres (230 miles) across surrounded by a ten-kilometre (28-mile) deep ocean under an icy crust. Initially, scientists thought the ocean was only present as an underground lake at the south pole, but Enceladus' slight wobble, or libration, shows that the rocky core is likely completely detached from the crust. This means the ocean envelopes the moon and probably accounts for 40 per cent of its volume. The reason the plumes only occur at the south pole is that the surface ice is believed to be much thinner – just five kilometres (3.1 miles) thick compared to the 20 to 45 kilometre (12 to 28 miles) thick surface across the rest of Enceladus. If this view of the moon is correct, Saturn's tidal heating wouldn't be enough to explain its liquid ocean. There may be more geothermal heat coming from the core than thought. This might help generate hydrothermal upwellings of nutrients and organic molecules, offering hope that life evolved there.

**1 Tidal heating** Gravitational flexing and friction from Saturn generate heat deep within Enceladus' rocky core.

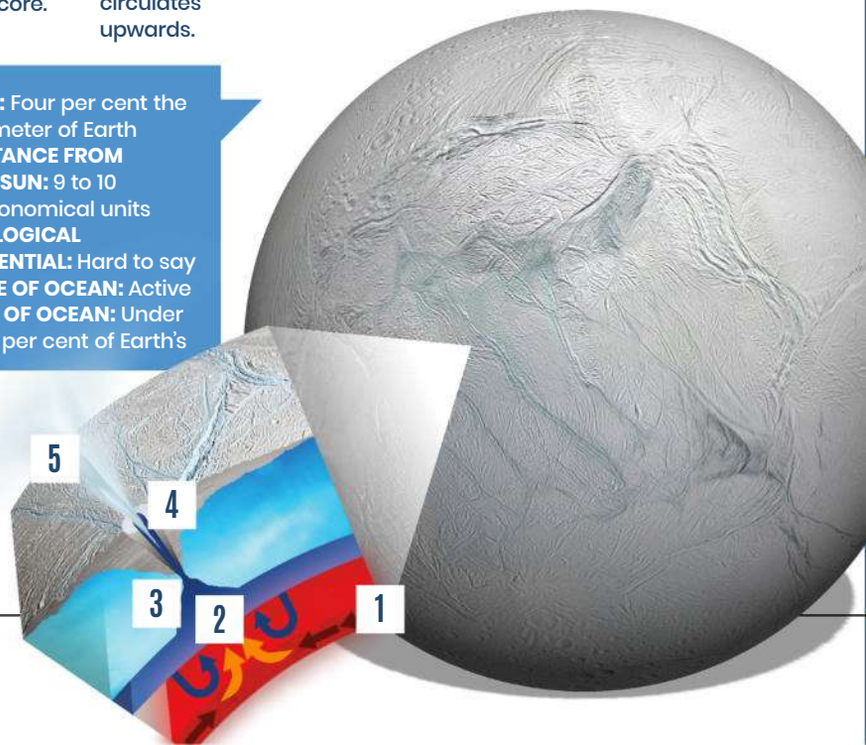
**2 Hotspot** Convection currents produce hotspots closer to the surface as the magma circulates upwards.

**3 Pressurised water** The icy crust melts on the underside and the water becomes pressurised as it expands.

**4 Vent** As the ice thins, a narrow vent forms connecting the water to the surface.

**5 Plume** Water vapour and ice crystals erupt with enough force to escape Enceladus' gravity.

**SIZE:** Four per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 9 to 10 astronomical units
**BIOLOGICAL POTENTIAL:** Hard to say
**TYPE OF OCEAN:** Active
**SIZE OF OCEAN:** Under one per cent of Earth's

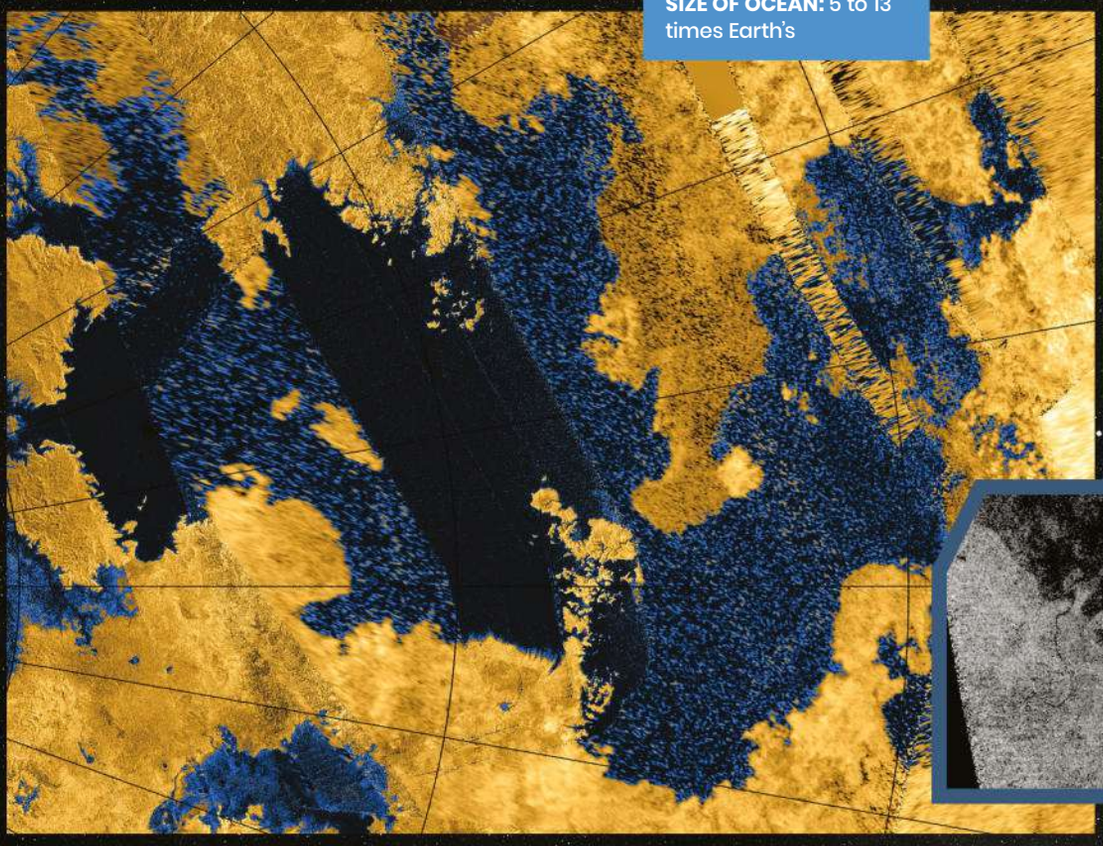


# TITAN

Titan is unusual because it's the only body in the Solar System, besides Earth, that has a substantial atmosphere and surface liquid. Titan's surface temperature is -180 degrees Celsius (-292 degrees Fahrenheit), so it's far too cold for liquid water on the surface, but it's just about right for liquid methane and ethane. These organic compounds evaporate into the atmosphere and rain down to form rivers, lakes and seas. The lakes and rivers only cover about three per cent of the surface, so Titan is still much drier than Earth. Titan's thick, orange haze comes from sooty tholin particles formed when the Sun's ultraviolet light breaks up the methane in the atmosphere. This ought to have used up all the methane on the surface billions of years ago, so Titan must have some underground reservoir that is replenishing it. However, scientists haven't found any strong evidence of cryovolcanoes that could be supplying this methane.

Like Callisto, Titan may have an ocean that's kept liquid by the antifreeze effects of dissolved ammonia. It would be equally hard for life to evolve there, as the liquid ocean is probably sandwiched between solid, impermeable ice layers. Life might have evolved in the hydrocarbon seas on the surface, but without access to liquid water, it would have a very different chemistry to life on Earth.

**SIZE:** 40 per cent the diameter of Earth
**DISTANCE FROM THE SUN:** 9 to 10 astronomical units
**BIOLOGICAL POTENTIAL:** Hard to say
**TYPE OF OCEAN:** Trapped
**SIZE OF OCEAN:** 5 to 13 times Earth's



Kraken Mare is Titan's largest sea, with a surface area larger than the Caspian Sea

Flooded canyons drain hydrocarbons into Titan's seas, eroding the canyon walls like rivers do on Earth

© NASA

FOCUS ON

# HOW NASA'S OSIRIS-REX MISSION WILL HELP PROTECT EARTH AGAINST ASTEROID BENNU AND ITS FLYBY IN 2182

## Could Bennu hit Earth in 2182?

Reported by Tereza Pultarova

Asteroid Bennu is a scientific gem, but a potentially dangerous one. No other space rock has a higher known probability of hitting Earth in the next 200 years. NASA's OSIRIS-REx asteroid-sampling mission will help scientists better understand how to protect humankind if Bennu's trajectory were ever to intersect with that of our planet. Bennu, discovered in 1999, is a rare B-type asteroid that's rich in carbon material believed to contain chemical compounds from the early epochs of the Solar System. On top of that, its orbit makes Bennu the most dangerous known asteroid in the Solar System.

Bennu is large enough to cause significant destruction on Earth. If it hit us, the space rock would punch a crater several kilometres wide into the planet's surface. The impact would also spawn an earthquake and a shock wave through Earth's atmosphere, which together would likely damage buildings hundreds of kilometres away from the impact site. The good news is that the chances of the rock actually hitting our planet anytime soon are very slim. Models of Bennu and Earth's orbital trajectories show that the paths of the two bodies might intersect in the year 2182, though they probably won't. The impact probability in that year is just 1 in 2,700. And even if those low odds hit – or revised models peg the risk as increasing – engineers and scientists still have plenty of time to figure out how to deal with Bennu.

Data collected by OSIRIS-REx will play a key role in shaping a potential Bennu deflection mission if it were ever needed. When OSIRIS-REx touched down on Bennu to snatch its sample in October 2020, the rock's surface responded in an unexpected way. Retreating almost like water, the mass of gravel inside the crater in which OSIRIS-REx landed, called Nightingale, nearly swallowed the spacecraft. That showed scientists that the surface layer of the asteroid has a surprisingly low density. The spacecraft sank 50 centimetres (20 inches) into Bennu's surface before its backaway thrusters fired. The escape manoeuvre triggered another unexpected response: images from OSIRIS-REx's onboard cameras revealed that a massive cloud of gravel and sand rose into space, threatening the spacecraft.

Scientists are comparing measurements from Bennu with data collected during NASA's Double Asteroid Redirection Test (DART), which successfully altered the orbit of the asteroid moon Dimorphos around its parent space rock Didymos in September 2022. "When I saw the images of Dimorphos, it looked really familiar; it looked like a bouldery pile of rubble with that same kind of characteristic texture," Dante Lauretta, OSIRIS-REx's principal investigator, said. "The [DART] mission was phenomenally successful.

It imparted a lot of momentum to the asteroid and substantially slowed its orbital velocity, and a large part of that is because there was so much material that was ejected from the surface, and that transfer of energy resulted in a significant change of the orbital period."

OSIRIS-REx's in-depth investigation of Bennu from orbit also revealed that the rocks towering on the asteroid's surface are made of a very porous sponge-like material. This porosity may be protecting Bennu from disruption by the impacts of other bodies. "It's like a crumple zone in a car," Edward Beau Bierhaus, a research scientist at Lockheed Martin, which built the OSIRIS-REx spacecraft for NASA, said. "The energy of that impact, rather than being distributed broadly into the surface and into the subsurface, can be absorbed by that single porous boulder." As a result, there are fewer craters on Bennu's surface than scientists expected based on their knowledge of how common asteroid collisions have been throughout the history of the Solar System. These strange qualities of the material that makes up Bennu could also affect how the rock would respond to a potential attempt to nudge it away from a collision course with Earth.

OSIRIS-REx studied Bennu up close for two years, and scientists are still studying the information it gathered there, and they'll be poring over the mission's asteroid sample, which landed on Earth on 24 September, for decades to come. "I think that people of the future will be well-equipped to deal with Bennu, especially because of the enormous amount of information that we have collected," Lauretta said. "I like to think of it as one of our gifts to the future generations."

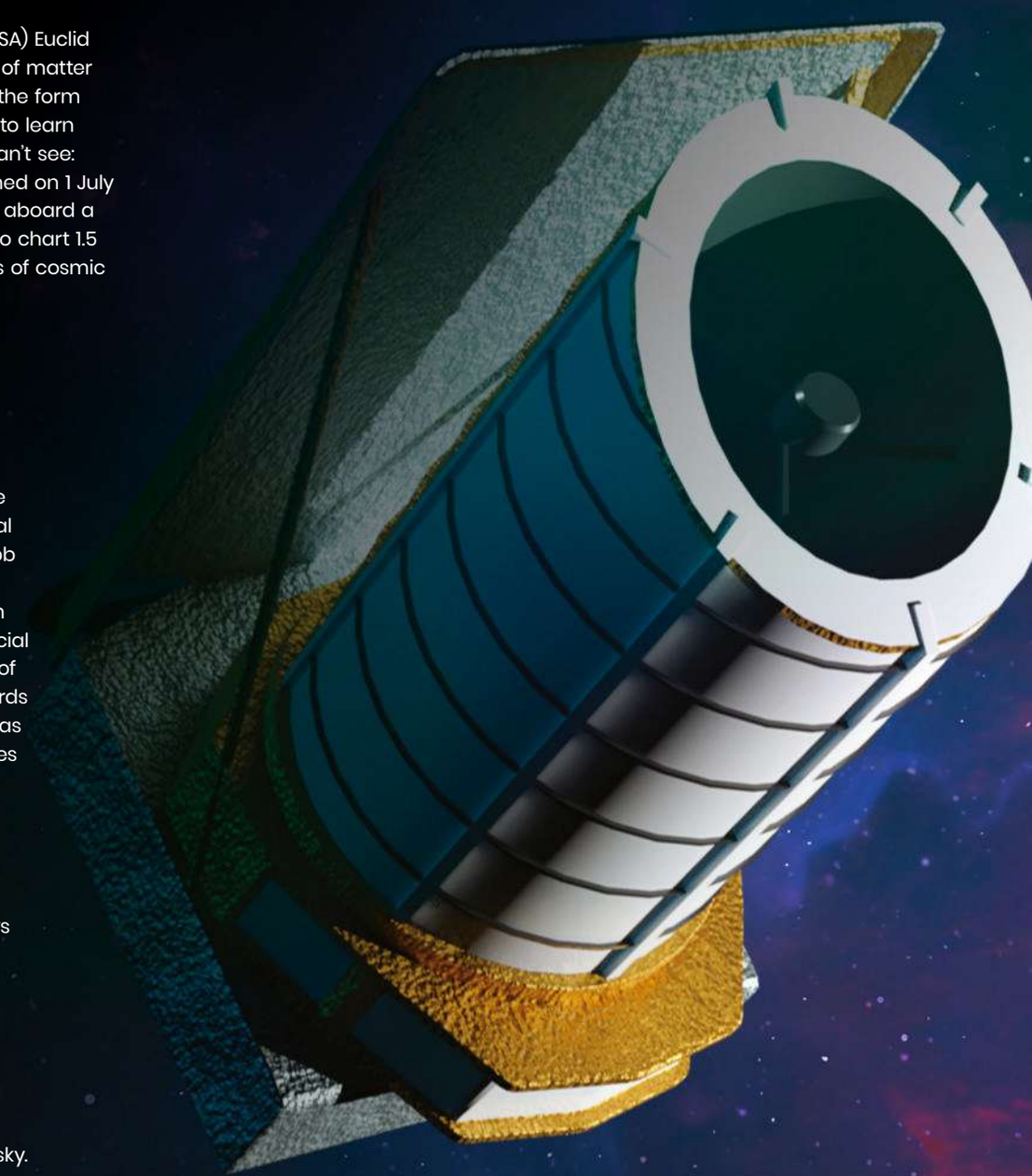
© Getty

# EVERYTHING YOU NEED TO KNOW ABOUT EUCLID

## This space telescope will shed light on the dark universe

Reported by Tariq Malik

The European Space Agency's (ESA) Euclid mission will map the geometry of matter in the universe – specifically in the form of the distribution of galaxies – to learn more about the parts of the universe we can't see: dark energy and dark matter. Euclid launched on 1 July at 15:12 (UTC) from Cape Canaveral, Florida, aboard a SpaceX Falcon 9 rocket. The mission aims to chart 1.5 billion galaxies over the past 10 billion years of cosmic history over its expected six-year lifetime.



## WHERE DID EUCLID GO?

It took roughly 30 days for Euclid to make its way to its destination at the L2 Lagrange point – the same location shared by several other spacecraft, including the James Webb Space Telescope. L2 lies about 1.5 million kilometres (930,000 miles) from Earth, but in the opposite direction to the Sun. It's a special location because it's at L2 that the gravity of Earth and the Sun balance, with the outwards centrifugal force acting on the spacecraft as it swings around Earth in its orbit. This makes the location quasi-stable – the spacecraft doesn't get flung deeper into space, but it does require manoeuvring thrusters for station keeping.

L2 also provides a clearer view of deep space, with the Earth, Moon and Sun always behind the spacecraft. This is essential if Euclid is going to succeed in its mission of charting 1.5 billion galaxies over the past 10 billion years of cosmic history, producing an image quality four times sharper than comparative ground-based surveys. As a survey mission, Euclid will last at least six years and cover 15,000 square degrees of sky. Its survey will be performed in a 'step-and-stare' mode, meaning that the telescope will point and make measurements on about 0.5 square degrees of the sky at a time.

## WHO IS THE EUCLID MISSION NAMED AFTER?

It's fitting for a space mission that will be mapping the geometry of the universe to be named after the father of geometry. The Greek mathematician Euclid of Alexandria lived during the time of Alexander the Great, and although the known details of his life are sketchy at best, his legacy was the invention of geometry as a mathematical subject. Euclid invented what we refer to today as Euclidean geometry, which is the basis for mathematical fields such as trigonometry. The universe also has Euclidean geometry. Measurements by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) show that the universe is 'flat' and does not have curvature like a sphere or a saddle. Parallel lines remain parallel forever, and the interior angles of triangles always add up to 180 degrees.

## WHAT WILL EUCLID DO?

Euclid will show scientists more about the 'dark universe'. One of its main goals is to accurately map galaxy redshift – the stretching of light to redder wavelengths as an object moves away from us, as is the case as the universe expands in all directions. Hubble's law tells us that the distance to a galaxy is related to how fast the expansion of the universe is carrying that galaxy away from us, and the higher the recession velocity, the more distant the galaxy and the higher its redshift. Measuring this redshift tells astronomers the rate of the universe's expansion and the strength of dark energy as it accelerates that expansion. The mission will look back to galaxies that existed as long as 10 billion years ago, with a redshift of about 2.0, or more than double the Solar System's age. Over at least six years, Euclid will map about 36 per cent of the sky and perform an extra-deep survey across three smaller fields of the sky totalling 40 square degrees.

Euclid's detectors will conduct two cosmological probes. One will study weak gravitational lensing – the marginal bending of light by concentrations of matter. This is useful for mapping the location of dark matter around galaxies and galaxy clusters by measuring how much the galaxy images are distorted by lensing. The other probe will study baryonic acoustic oscillations (BAO), relics of fluctuations in the cosmic microwave background (CMB) radiation that today manifest themselves in the spatial distribution of galaxies. Across very large scales, galaxies tend to cluster in pairs separated by a standard distance. This standard distance is linked to sound waves in plasma, or ionised gas, in the early universe; the sound waves propagated as density waves through the plasma and are linked today to the locations of dark matter halos, or concentrations of dark matter associated with galaxies. The size of this standard distance increases over time as the universe expands, so BAOs are a standard ruler to measure the universe's expansion, and hence the strength of dark energy at different eras in cosmic history.

# Q&A

## GIUSEPPE RACCA

### Racca is the European Space Agency's Euclid project manager

**How will the Euclid mission improve our understanding of dark energy?**
Dark energy is essentially a nickname for something that makes the universe expand in an accelerated fashion. This acceleration seems to have kicked off about 5 billion years ago and was discovered by observing from ground observatories the recession velocity of distant galaxies. The acceleration behaviour is consistent with a sort of 'repulsive' energy of the vacuum with constant density or a cosmological constant of the general relativity equations, which describe gravity as a matter versus space-time geometry relationship. Euclid will improve our understanding essentially by measuring whether the dark energy density is really constant over the last 10 billion years.

**What will mapping galaxies teach us about dark matter?**
Dark matter is the predominant form of matter in the universe. Without it, the stars probably wouldn't have formed in

© Getty;

# ALL ABOUT THE EUCLID SPACECRAFT

4.5 metres (14.7 feet) tall and 3.1 metres (10.2 feet) in diameter, Euclid is fairly modest compared to the size and complexity of the James Webb Space Telescope. Euclid's science will be performed by two instruments, and its onboard 1.2-metre (3.9-foot) telescope will capture and split light between them for analysis. One of these instruments is a visible imager (VIS), which will include 36 charge-coupled devices (CCDs) specially formulated for the mission. The field of view of VIS is 0.787 degrees by 0.709 degrees. The second instrument is a near-infrared spectrometer and photometer (NISP) that will provide near-infrared photometry of galaxies. The aim is to combine VIS and NISP's observations to accurately measure the redshift of galaxies. NISP will also investigate the chemistry of galaxies and the motion of stars and gas within them to find out how galaxies spin and shed light on how they formed.

**0.36**
The total area of sky that Euclid will observe during its 6.5-year mission life

**850**
The number of gigabits of compressed data that Euclid will collect per day

**10 BILLION**
The number of years into the universe's past that Euclid will look into

**1.2**
Diameter of Euclid's Korsch telescope mirror in metres

## 1 Sunshade
Vital electronics will be protected by a sunshade mounted on one side of the telescope. Because this side is perpetually facing the Sun, solar panels will be mounted to provide energy for the telescope.

## 5 Telescope mirror
A large mirror will collect information about the bending of light around large fields of gravity, as well as galactic structures. The aim is to learn more about dark matter and dark energy.

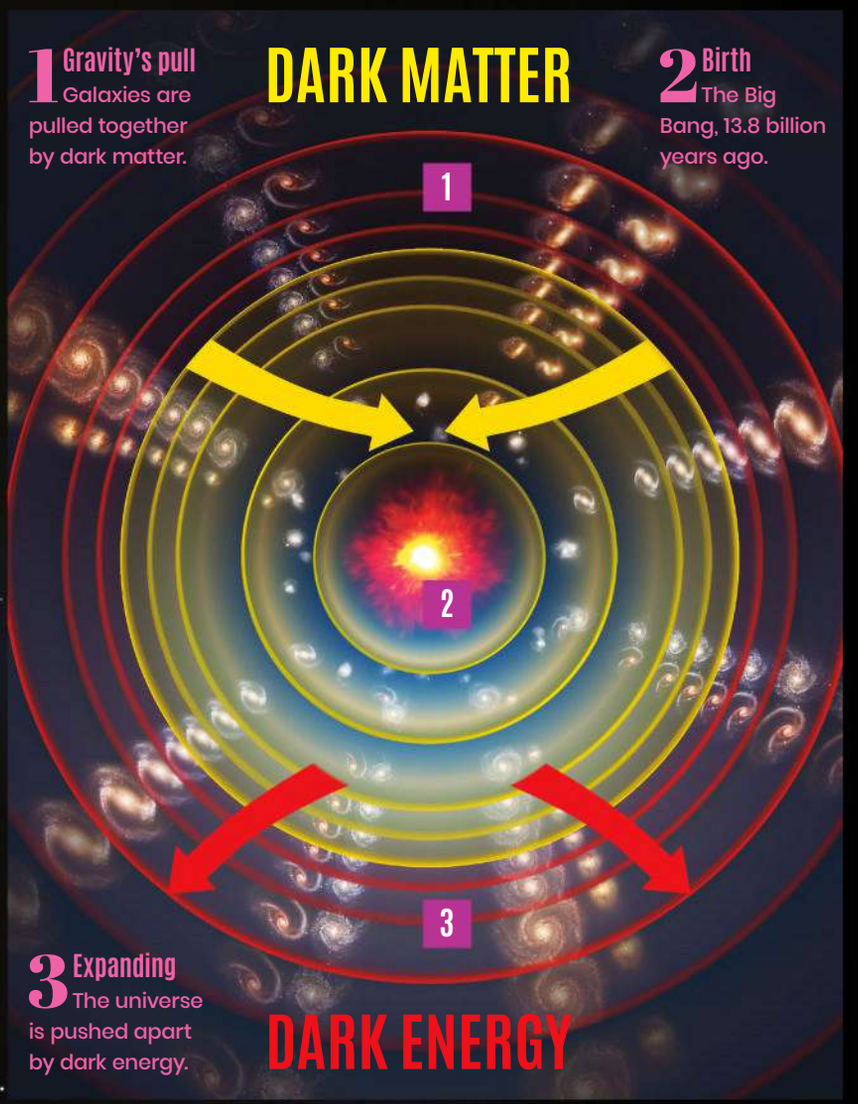
## 2 A stable spot
Euclid will be at a Lagrange point, a stable point of gravity 1.5 million kilometres (930,000 miles) from Earth. It will stay close to the L2 point, remaining relatively stationary except for occasional adjustments.

## 3 Science instruments
Euclid will have two principal science instruments: an optical camera that does photometry and a camera that will peer into the near-infrared, performing photometry and spectrometry.

## 4 Reflective material
Much of the telescope will be covered in material to reflect the heat of the Sun and keep the electronics and other components inside cool.



**1.5 MILLION**
Euclid's distance, in kilometres, from Earth in its operational orbit




## WHAT ARE DARK MATTER AND DARK ENERGY?

Dark energy and dark matter make up most of the mass and energy in the universe. Dark matter is an unseen substance, the presence of which we can only infer from its gravity. Dark matter contributes about 26.8 per cent of all the matter and energy in the universe. Dark energy, on the other hand, is a mysterious energy field that is accelerating the expansion of the cosmos and accounts for about 68.3 per cent of all the mass and energy in the universe. The remaining 4.9 per cent is everything else that we can see in the universe – people, planets, stars, nebulae and galaxies. Together, dark matter and dark energy affect the geometry of the universe. Clumps of dark matter create gravitational wells that can bend the otherwise-straight paths of light from more distant objects, while by driving the accelerated expansion of the universe, dark energy pulls clumps of matter away from one another, lowering the overall density of matter in the cosmos. By measuring how they affect the universe, astronomers can gain important insights into their puzzling natures.

the early universe, and the presence of dark matter across the universe is essential to all cosmic structure formation. Dark matter is not visible and does not absorb radiation, but deflects light because of its gravitational pull – more exactly because of its warping of space-time – and deforms the shape of the galaxies as seen by the observer. This effect is called weak gravitational lensing. By observing distant galaxies whose light has travelled through the dark and regular matter from the source to us, we can measure the distribution of dark matter in its path. By doing this with billions of galaxies, Euclid will build a full map of the distribution of dark matter in the entire universe.

> "Dark matter is not visible and does not absorb radiation"

**How does Euclid differ from other dark energy studies?**
There are indeed many cosmological surveys, mainly on the ground and one planned from space – NASA's Roman Telescope. Euclid's quality is in its image sharpness, which allows it to minimise the systematic errors concerning the aforementioned weak lensing probe. Moreover, the Euclid telescope's characteristic design allows it to cover a large amount of the sky in a relatively short time with unprecedented accuracy and precision. Concerning the spectroscopic capability, Euclid will also make observations of light from galaxies at near-infrared wavelengths, which is absorbed by the atmosphere and therefore not visible from the ground. This capability is used to accurately measure the recession velocity of hundreds of millions of galaxies as far as 10 billion light years.

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FOCUS ON

# THE VLT FINDS A SURPRISE EXOPLANET IN A THREE-BODY STAR SYSTEM

## Astronomers made an unexpected discovery when reanalysing images taken by one of the world's largest telescopes

Reported by Tereza Pultarova

The Very Large Telescope (VLT) in Chile has photographed a planet orbiting a star in a multi-star system located some 480 light years from Earth. The exoplanet, 15 times more massive than our Solar System's largest planet, Jupiter, orbits a small star that itself orbits a larger star. Also orbiting the larger star is a brown dwarf, or failed star. Brown dwarfs are given such a gloomy moniker because these objects aren't massive enough to sustain nuclear fusion in their cores like typical stars, but are still too large to be called planets.

The system of two stars and a brown dwarf, collectively called HIP 81208, has been known to astronomers for a long time. But the existence of an exoplanet in orbit around the smaller star came as a surprise to astronomers, who recently re-examined images of the system taken earlier by the European Southern Observatory's (ESO) Very Large Telescope in Chile. The team's discovery marks the first hierarchical quadruple system to be found using direct imaging.

Most exoplanets are discovered through the so-called transit method, which involves observing subtle dips in a star's brightness caused by a planet passing in front of its disc from the point of the observer. Direct imaging is essentially traditional photography. However, astronomers use this method to capture deep-space worlds using very powerful telescopes and super-sensitive cameras to see planetary subjects directly. In the reanalysed images, astronomers from the Paris Observatory detected the giant exoplanet creating a blob in the ring of light surrounding its parent star. The discovery will help astronomers further their understanding of the formation of complex systems.

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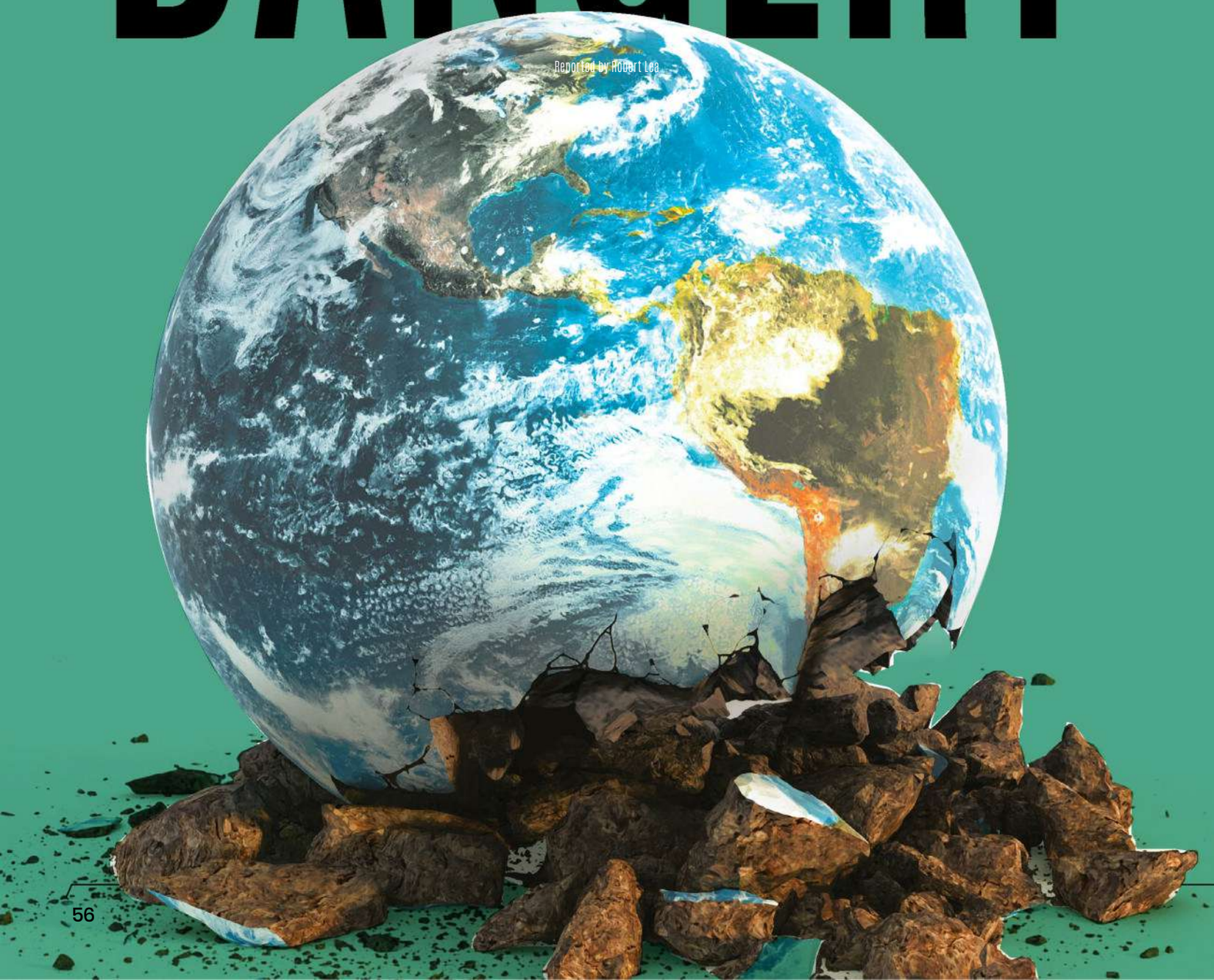
# IS EARTH IN DANGER?

**A first-of-its-kind 'scientific health check' shows global life-support systems are outside the limits at which humanity evolved and civilisation emerged**

Reported by Robert Lea

Reported by Robert Lea



For the last ten millennia, humanity has existed in a fine balance with Earth, with the actions of our species affecting aspects of Earth's system, such as climate and the existence of other forms of life, all of which also impact this finely tuned natural machine. Since the Industrial Revolution, however, humanity's relationship with the Earth system has been skewed out of balance. As a species we put more waste back into the system than it can handle while simultaneously removing vital elements, such as habitats needed by other species, which simultaneously deletes these species with an intensity currently approaching that of mass extinctions previously experienced by our planet.

Now, the first comprehensive 'global health check' has revealed that Earth and its life-support systems are "now well outside of the safe operating space" for humanity as a result of this one-sided relationship with nature. The research suggests the planet's resistance to humanity's influence is failing, something which could threaten the goal of keeping global warming below 1.5 degrees Celsius (2.7 degrees Fahrenheit) – a key tipping point for Earth, beyond which lies a dramatic increase in the risk of events such as extreme flooding, drought, wildfires and food shortages. These dramatic changes signal the beginning of a new epoch for humanity and for Earth as a whole.

An overview of around 2,000 individual studies, with the work published in the journal *Science Advances*, indicates that Earth is heading into the Anthropocene epoch, which despite being named after humanity – anthro comes from the Greek word for 'man', or 'human' – may be disastrous for our species and life in general. The team behind the research, led by University of Copenhagen researcher Katherine Richardson, found that six of nine key planetary boundaries have been exceeded, with the reason for these violations identified as human activities.

The limits represent levels for these boundaries slightly above those found globally during the Holocene epoch and are what's required to keep Earth safely in an interglacial state similar to that found across the globe during this time period. This is significant as it was during the Holocene, which began around 11,700 years ago at the end of the last major ice age, that the entirety of human agriculture and civilisation developed. While humanity has demonstrated its ability to exist and function over the relatively stable and warm planetary conditions characterised by the last 10,000 years, the conditions that will define the Anthropocene epoch are uncertain, as is our species' ability to prosper under more dramatic changes to the Earth system that could lie ahead. The boundaries were established in 2009 and then revised in 2015, but prior global health checks had only been able to consider seven of the nine parameters this study looked at.

Stockholm Resilience Centre researcher Sarah Cornell, one of the authors of the study, explains to **All About Space** that prior to this report there was just not enough information to assess and quantify some parts of this global framework properly, meaning this is the

Liddell Power Station, one of Australia's oldest coal-fired power plants, closed in April 2023. It will be the site of a new low-carbon industrial energy hub

## BROKEN OPERATING PARAMETERS FOR EARTH

**Stockholm Resilience Centre scientist Sarah Cornell explains that six of the nine identified planetary boundaries for Earth have exceeded safe operating parameters**

### 1 Loss of biosphere integrity

"Extinctions are forever!" Cornell says. "And whether we consider impacts on species, populations, habitats or the really big picture of life's effects on the global cycles of carbon, water and other elements, today's human activities have unprecedented and intensifying effects on the biosphere."

### 2 Climate change

Arguably the most familiar planetary boundary, models of the climate suggest this boundary was crossed in the 1980s. Humanity's influence on climate change is mainly driven by the amount of greenhouse gases we pump into the atmosphere, such as methane and carbon dioxide.

### 3 Novel entity concentrations

This refers to human-caused pollutants in the form of synthetic materials that are new to the planetary ecosystem. This boundary was found to have been crossed by a study in 2022. "These entities were not in the Earth system until they were synthesised or mobilised by human activities," Cornell says.

### 4 Biogeochemical flows

This involves mainly the flow of nitrogen and phosphorus, which can have a detrimental impact when found in excess. Cornell adds that today's nitrogen and phosphorus flow levels mean that the basic chemistry of life that sustains the world's ecosystems is out of balance.

### 5 Land use changes

This describes how land functions. Examples are the razing of forests and other natural habitats to create farmland and urban areas. "This describes how deforestation changes ecosystems and their roles in climate and the global cycles of carbon, water and other elements," Cornell says.

### 6 Freshwater changes

"Freshwater use is changing both the 'blue' water that most of us think about when we think of water in the environment, and also the 'green' water that is transported through vegetation," Cornell says. "Changing the stocks and flows of water changes what vegetation is possible."

© Science Photo Library / Getty

An aerial image of Makua Reef on the north shore of Kauai, Hawaii, a coral reef suffering due to ocean acidification

# LIVING ON THE EDGE

## What will be the next operating parameter for Earth to be broken?

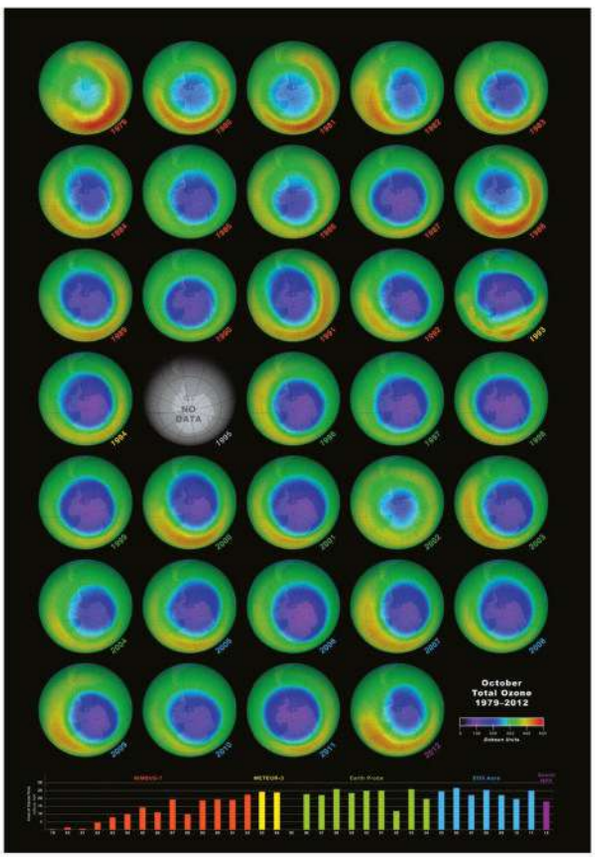
In addition to the six broken boundaries, this global health check also found two boundaries are approaching safe operating limits. Closest is ocean acidification, which refers to the reduction in the pH of Earth's oceans. Acidification is something that's primarily driven by the absorption of carbon dioxide from the atmosphere. This causes an increase in hydrogen ions in water and a reduction of carbonate ions. Carbonate ions are important for sea life with shells and coral skeletons, so this reduction can impact organisms like oysters, clams and deep-sea corals.

The impacts of ocean acidification are already being felt by oceans worldwide, and could impact economies that are dependent on fish and shellfish – many people worldwide rely on food from the ocean. Also close to moving outside its safe operating zone is the amount of atmospheric air pollution. The team found that the amount of particles in the atmosphere in regions such as South Asia and China exceeded this limit, but this is not yet apparent globally.

first time scientists have produced a full health check for Earth including all these nine parameters. "Another first is that new global modelling lets us track and map changes that result from Earth system interactions as the framework's key processes change over time," Cornell explains. "All these environmental change processes are driven by human activities, and the human impact is both detectable against the long-term baseline of Earth system functioning and attributable, on aggregate, to these activities."

In addition to the six broken planetary boundaries, the scientists also identified two parameters that are close to breaking point: ocean acidification and aerosol particles in the atmosphere. Richardson tells **All About Space** that the changes driving the breaking of these parameters are related to humanity's waste production and what we as a species take out of the Earth's energy system. She cited climate change as a human waste problem, with that waste being our greenhouse gas emissions, and with air pollution and novel entity production also being examples of how waste production influences our relationship with the global environment.

"Nature has had 3.7 billion years to make its 'final machine', and there's no waste in nature's machine because there is always an organism to use that waste and return waste to a form that can go back into the system and be used," Richardson says. "Nature is a circular economy, if you will." Richardson adds that the boundaries not concerned with waste focus on what humanity is removing from the Earth system




The hole in the ozone over Antarctica as seen between 1979 and 2012 by NASA satellites

# WHAT'S HAPPENING TO EARTH?

**We can already see some of the measurable effects of climate change on the planet**

## 97%

### Scientific consensus

Most climate experts agree climate trends observed over the last century are a result of human activity.

## 286

### gigatonnes per year

### Ice sheets

The Antarctic and Greenland ice sheets have been losing mass since 2002, with 127 and 286 gigatonnes lost respectively per year since.

## 2016

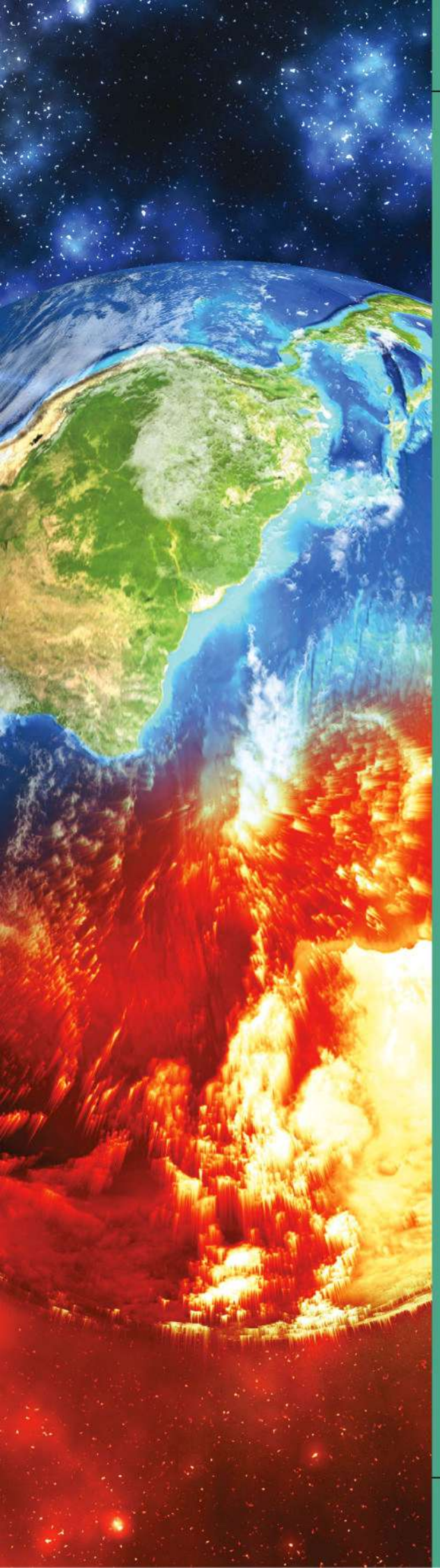
### Global warming

2016 was the hottest year on record. 2017 was the second warmest and 2015 the third hottest.

## 30%

### Biodiversity

Since Europeans started to colonise the Americas over 500 years ago, 30 per cent of biodiversity has been lost. This is expected to rise to 40 per cent unless steps are taken.



**3.2**
**millimetres**
**Sea level**
Sea levels are rising at a rate of 3.2 millimetres a year.

**10%**
**Vegetation**
Scientists estimate that around ten per cent of global carbon dioxide emissions come from deforestation.

**250,000**
**Disease**
Between 2030 and 2050, climate change is expected to cause 250,000 more deaths per year due to conditions like malaria and malnutrition.

**1°C**
**Temperature**
The world has warmed by about one degree Celsius (1.8 degrees Fahrenheit) since 1880.

**408**
**parts per million**
**Pollution**
Atmospheric carbon dioxide levels measured at Mauna Loa Observatory, Hawaii, continue to increase, with the latest recording in February 2018.

as a result of its activity. Examples of this would be the destruction of habitats that are resulting in the extinction of animal and plant species – defined as the loss of biodiversity by the team.

Richardson and her colleagues believe that humanity started to shatter this circular economy when our ancestors started living at a 'fixed address' and initially started just dropping their waste where it was produced and taking whatever they wanted from the environment. Eventually, humanity had to learn to manage its interactions with the local environment, and part of this meant not taking more out of the system than is necessary – for instance, not over-killing animals for food. With Earth's population now standing at over 8 billion people, Richardson says that this relationship between humanity and the Earth's energy system has to be redefined. She adds that this is something our species will have to do for the entirety of its existence going forward, hence why understanding these planetary boundaries are so crucial. "This isn't for the sake of our planet," she continues. "It's for the sake of ourselves."

For Richardson, the report doesn't represent complete doom and gloom. She thinks there's hope that with remedial action, humanity could drag the planet back to the right side of at least some of these safe operating limits, adding that most of these parameters are not tipping points. "We emphasise the point that being on the wrong side of these boundaries is not necessarily a recipe for certain disaster," Richardson says. "If your blood pressure is high, say, 120 over 80, it's no guarantee you're going to have a heart attack, but it does increase the risk. And it's exactly the same with the planetary boundaries."

The only one of the nine planet boundaries focused on by the team that isn't currently broken or close to its limit – atmospheric ozone – is an example of the power of remedial action. In the 1980s, it was discovered that the ozone layer over Antarctica had been reduced in thickness compared to previous decades. This thinning was labelled the 'ozone hole' and was linked to the emission of chlorofluorocarbons (CFCs) used in aerosols and air conditioning devices.

This was regarded as a global crisis because ozone in the second-lowest layer of the atmosphere, called the stratosphere, helps protect Earth – and thus humanity – from the most harmful radiation from the Sun. Thanks to action to limit CFCs in the atmosphere, including 1987's Montreal Protocol, the ozone hole is shrinking, though

© Getty

An area of forest in Indonesia was burned in 2018 for a palm oil plantation

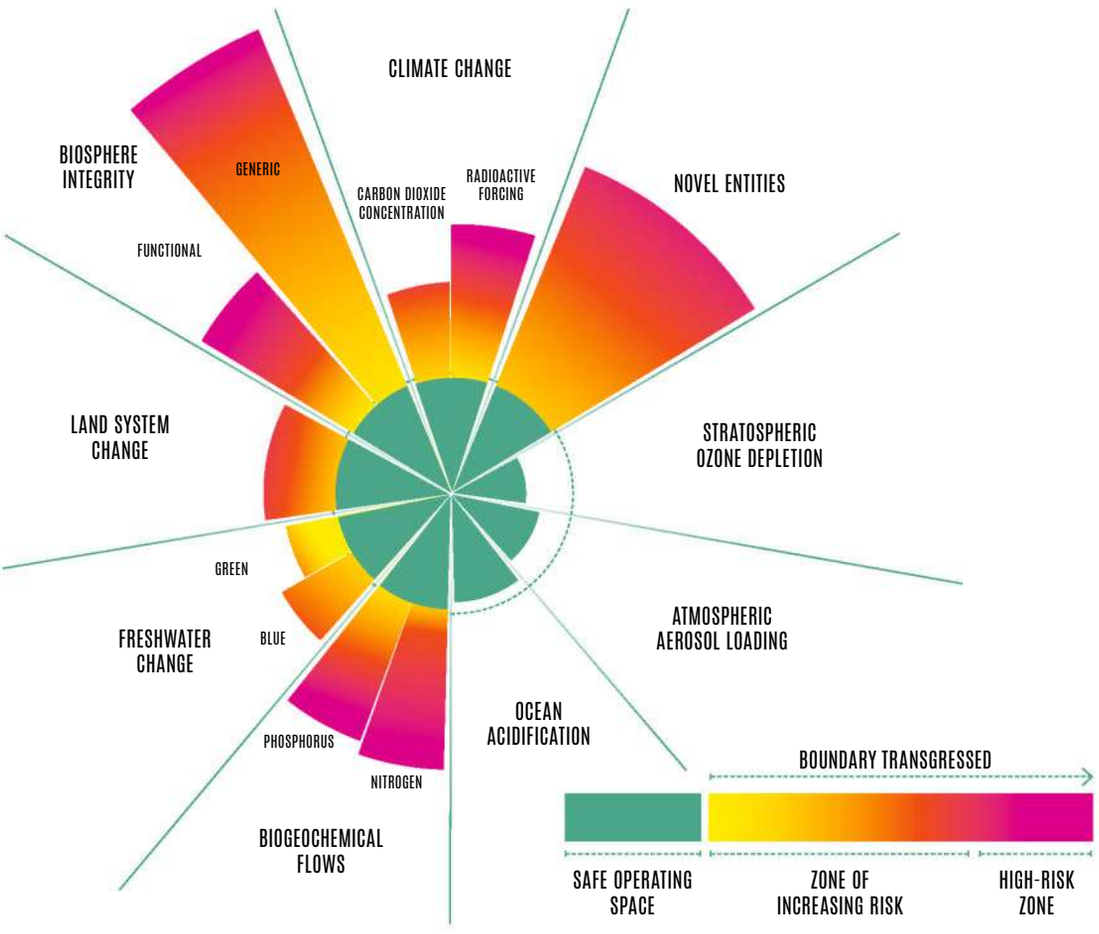
Nine planetary boundaries defining a 'safe operating space' for humans

the ozone layer may never completely recover. "In the 1990s we were either on the wrong side or very close to being on the wrong side of the ozone boundary thanks to the ozone hole," Richardson says. "We're now in the safe operating space for atmospheric ozone, so we reversed the boundary crossing in that case."

There's one broken boundary that Richardson highlights as being irreversible, and this is the one she is personally most concerned about. That is the loss of biodiversity – the variety of life on Earth in all its forms. Richardson adds that while a great deal of emphasis is placed on Earth's climate, and rightly so, all planets have climates, and what really makes Earth unique is the fact that it harbours life. Thus the interaction between climate and life is vitally important to our existence, and it's something Richardson feels is often overlooked. "Life transforms and transports elements, and every time that it has been possible to get free energy out of such a transformation, an organism has evolved to do just that," Richardson says. "That means for billions of years, conditions on Earth have pretty much been controlled by the interaction between climate and life."

As a result, biodiversity impacts the food humans eat, the air we breathe and even the climate – and thus our weather. And when a species is lost, that's a permanent situation with a permanent effect on the Earth system. "And when we get control over our emissions, and I honestly believe we will, the energy balance of Earth will go back to a state that doesn't have a human fingerprint on it," Richardson explains. "But when you lose a species, it's gone forever. We can never come back to a biosphere that doesn't have the fingerprint of humanity on it."

Pushing planet boundaries back to safe limits shouldn't be seen as a quick fix, though, at least according to Cornell, who is less confident that the damage perpetrated by human activities on these




# EVIDENCE FOR CLIMATE CHANGE

**Images taken from space highlight the impact on Earth**

### 1 Bering Strait sea ice changes

Three radar scans, in blue, red and green, show how sea ice changed over four weeks in 2017 to 2018.

### 2 Helheim Glacier melt, Greenland

Helheim Glacier is shown crumbling into icebergs, having retreated about 7.5 kilometres (4.6 miles) from 2001 to 2005.

### 3 Columbia Glacier melt, Alaska

Columbia Glacier has been in rapid retreat since 1980 and has thinned significantly.

### 4 Binhai new area growth, China

Astounding urban sprawl can be seen on China's coast between 1992 and 2012.

### 5 Shrinking Aral Sea, Central Asia

The Aral Sea was the fourth-largest lake in the world until the 1960s, when the Soviets diverted water for crops.

### 6 Nordenskiöld Glacier melt, Greenland

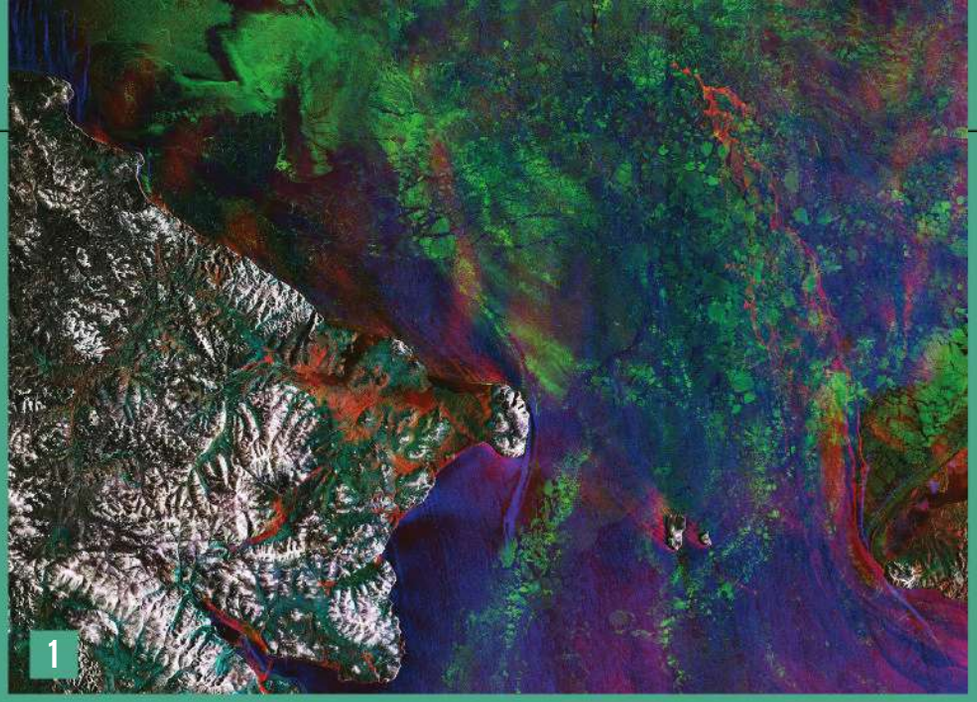
Nordenskiöld Glacier is just one of many glaciers draining Greenland's ice sheet.

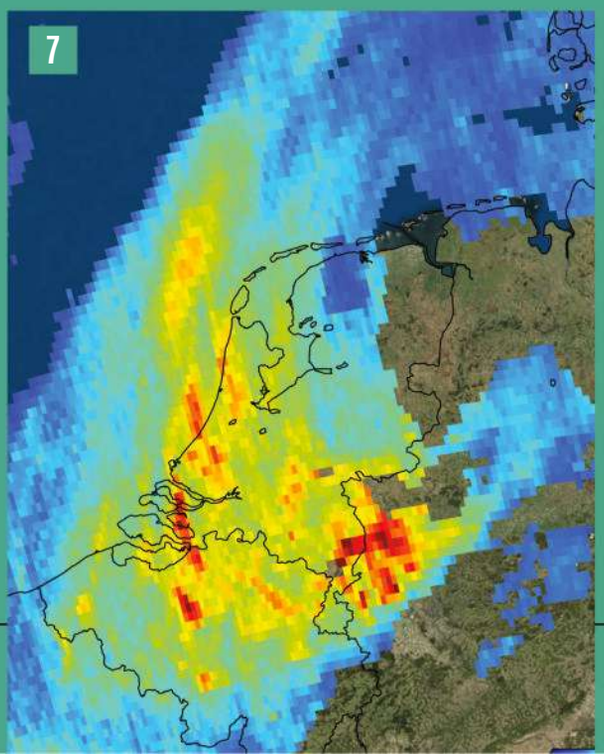
### 7 Nitrogen dioxide over The Netherlands

One of Sentinel-5P's first images shows high levels of atmospheric nitrogen dioxide over The Netherlands and west Germany.

### 8 Drying Lake Poopó, Bolivia

Bolivia's second-largest lake dried up again in 2016 due to drought and diversion of water sources.





© NASA; ESA; Wolfgang Kaehler/Getty Images

# EXTINCTION IS FOREVER

## The loss of species and biodiversity is irreversible

The fact that humanity can't currently bring species back from extinction means that the loss of biodiversity represents arguably the least reversible of the six broken planetary boundaries reported by the team. Earth could currently be in the midst of its sixth major mass extinction event thanks to human activity. It's estimated that since the 1900s, around 500 animal species have gone extinct, with the study authors estimating that without human influence, it would have taken between 800 and 10,000 years for this many species to be lost.

Some of the species lost during this rapid loss of biodiversity include Costa Rica's golden toad, the Caspian tiger, the Caribbean monk seal, Hawaii's O'ahu tree snail and the Pinta Island tortoise, which helped inspire Charles Darwin's theory of evolution by natural selection. It's estimated that around 1 million species face extinction as a result of climate change, habitat loss or pollution, all of which are driven by human activities.

One of the last photos of a golden toad, taken in 1978

© Getty

A polar bear stands on melting sea ice in a striking illustration of climate change's effect on animal habitats

parameters can be undone. Her pessimism stems from the complex and sometimes not fully understood ways in which these planetary boundaries are entwined. "Speaking as an Earth system scientist, the situation can't simply be reversed," she says. "Earth is a living planet, and its processes are fundamentally complex. Life adapts to its physical surroundings and to climate conditions, and in turn it changes the world's physical and climatic conditions." Cornell adds that the world's societies could act to mitigate the pressures on the planetary boundaries, and in some cases that might mean 'going back' by attempting to remediate damaged landscapes and water bodies, thus allowing fish stocks to recover and forests to regrow. "In most cases, societies need to both reduce the pressures and adapt to a changed world," she continues.

This same theme of an interwoven holistic Earth system that Cornell describes is also reflected by what she finds the most concerning element of the picture painted by the team's global health assessment. "It's a systemic story, so perhaps the most concerning aspect is that people, including policymakers, tend to treat each issue as separate," Cornell continued. "Multilateral policies already exist for all of the planetary boundary processes, reflecting international social and political concerns about the impacts of these processes. The climate and biodiversity conventions are probably the most well-known and influential, but they are also the ones where implementation gaps are getting extremely worrying!"

Cornell explains that the social impacts of all these planetary pressures are already severe and well documented in many global environmental and economic assessments, adding that biophysical trends are worsening. "The world's societies make choices about risks, preparedness and how people's hopes and needs can be met, which means that there's also a lot of scope for hope and action," Cornell concludes. "A systems perspective like the one taken in this paper is a way to bring these complex, co-existing social and environmental dimensions together."

**Robert Lea**
*Space science writer*
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

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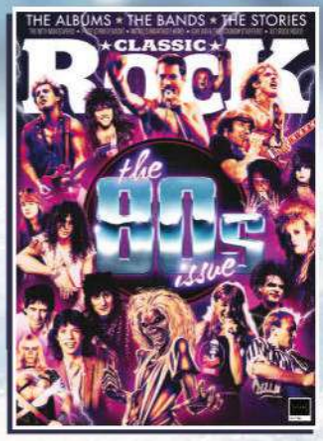

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FOCUS ON

# NEW DRUG SHOWS POTENTIAL TO AID ASTRONAUTS DURING FUTURE MISSIONS TO THE MOON AND MARS

**BP-NELL-PEG has shown promising results of combatting microgravity bone loss in mice. However, it's yet to be tested in humans**

Reported by Sharmila Kuthunur

Across the world, one person fractures a bone every three seconds due to a disease called osteoporosis, a common condition that weakens the bones of at least 10 million people in the United States alone. And with the concept of crewed space missions to the Moon and Mars gaining momentum, scientists are actively looking for ways to protect astronauts from the inevitable consequences of long-term spaceflight, including sharp reductions in bone density. While most drugs used to treat osteoporosis work by slowing the disease, a new approach that targets the formation of new bone has shown promising results. Moreover, those results were achieved in mice during an experiment done on board the International Space Station (ISS).

Researchers used a well-known protein produced by the body called neural epidermal growth factor-like 1 (NELL-1), which has previously demonstrated promotion of bone formation in some animal models. Because the drug works by harnessing this protein only when injected into an affected bone during surgery, researchers modified the drug so that it could be injected under the skin to promote bone formation throughout the body. "If human studies bear this out, BP-NELL-PEG could be a promising tool to combat bone loss and musculoskeletal deterioration, especially when conventional resistance training is not feasible due to injuries or other incapacitating factors," Dr Eric Kang Ting, a professor at the Forsyth Institute in Massachusetts and co-researcher of the new study, said. Ting first discovered the bone-forming effects of NELL-1 over 20 years ago.

The new study also enhanced the drug's potential by extending its half-life, which determines how long a drug can persist in the body. In this case, the half-life nearly tripled, going from 5.5 hours to 15.5 hours. The modified drug, termed BP-NELL-PEG, "displayed superior specificity for bone tissue without causing observable adverse effects," the scientists said. "We can unequivocally say that NELL-1 increases bone density in microgravity conditions, which is very exciting," Chia Soo, a professor in the departments of Surgery and Orthopedic Surgery at the University of California, Los Angeles, and lead author of the new study, said about the drug in 2018. "This success demonstrates the robustness of the therapy to treat extreme bone loss."

To test out the drug's effects for bone loss due to spaceflight environment, researchers flew 40 female mice to the ISS in 2017 and observed another 40 in the Kennedy Space Center in Florida that were treated with the drug but were not exposed to spaceflight conditions. Both of the groups "exhibited a significant increase in bone formation," the researchers said. Among the 40 mice on the ISS, 20 were returned to Earth alive after 4.5 weeks, while the other half continued to be exposed to microgravity for nine weeks. This marks the first time live mice were returned to Earth from space, which was important for the team in conducting analysis on live tissues and cells. While the drug has shown promising results in mice, however, there is still a long way to go before it can be used to help bone formation in humans.

Low-gravity environments affect humans down to the bone

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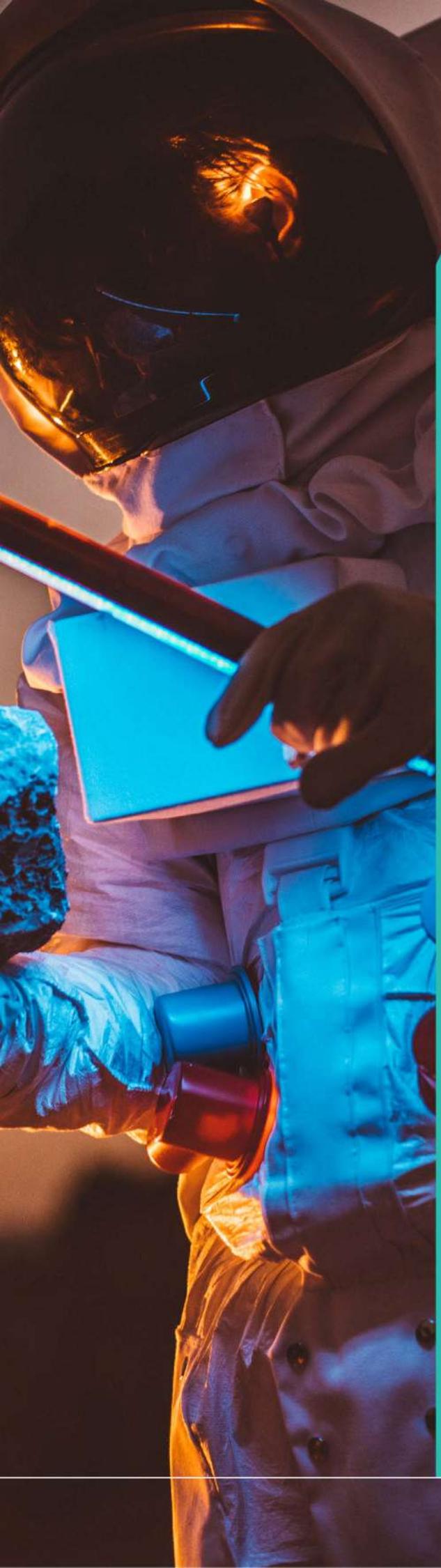


# HOW SPACE AFFECTS THE BODY

### IMMUNE RESPONSE
With a more potent immune response, women are more resistant to viral and bacterial infections, but are more susceptible to autoimmune diseases.

### VIIP SYNDROME
Although female astronauts have not shown significant visual impairment, that may be because so few women have been in space.

### ORTHOSTATIC INTOLERANCE
Dizziness comes from blood returning to the lower body and blood pressure in the head suddenly reducing on re-entry. Women are more susceptible to this.

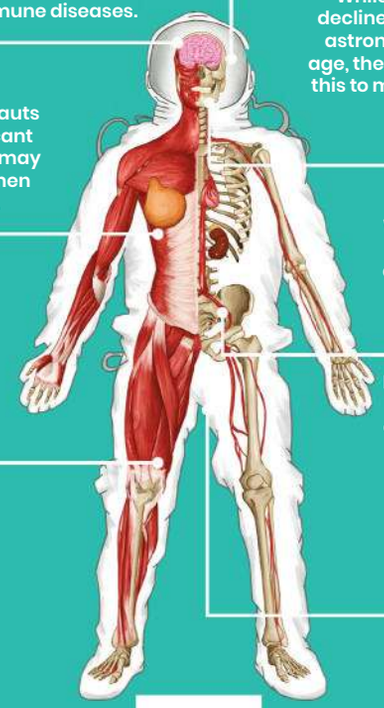
### MUSCLE AND BONE LOSS
ISS crew members engage in physical exercise for two-and-a-half hours a day, six times a week while in orbit to avoid these issues, though results depend on the individual.

### HEARING LOSS
While hearing sensitivity declines far slower in female astronauts with increasing age, there's no evidence to link this to microgravity exposure.

### ACCURACY VERSUS SPEED
Women demonstrate a slight bias towards accuracy versus speed in response to an alertness test.

### KIDNEY STONES
Due to decreased urine output, urine acidity and increased calcium excretion as a result of bone loss, kidney stones can develop. Struvite stones are more common in female astronauts.

### URINARY TRACT INFECTIONS
Astronauts probably don't drink as much as they should, sometimes leading to UTIs, which are more common in female astronauts.



FEMALE

### VIIP SYNDROME
During long spaceflights, over half of male astronauts experience visual impairment intracranial pressure (VIIP) symptoms.

### KIDNEY STONES
Kidney stones can range from tiny microscopic crystals to stones as large as walnuts, and cause excruciating pain. Calcium oxalate stones are more prevalent in men.

### URINARY TRACT INFECTIONS
Adapting to microgravity and with many important tasks to complete, some astronauts hold their urine, which contributes to UTIs.

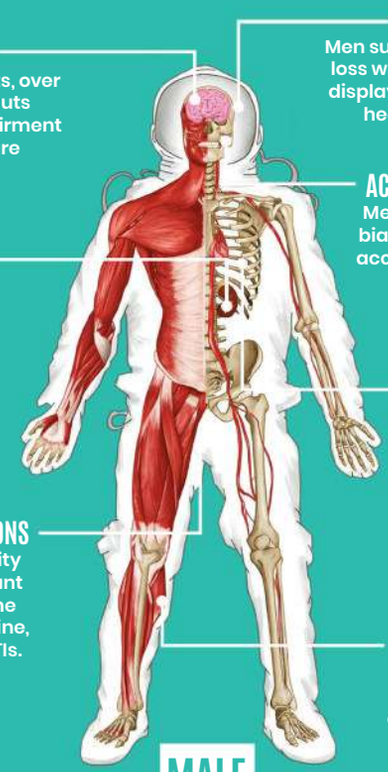
### IMMUNE RESPONSE
With a weaker immune response, men are less resistant to viral and bacterial infections.

### HEARING LOSS
Men suffer more from hearing loss with advancing age and display a bias towards loss of hearing in the left ear.

### ACCURACY VERSUS SPEED
Men demonstrate a slight bias towards speed versus accuracy in response to an alertness test.

### ORTHOSTATIC INTOLERANCE
Males are less susceptible, but 83 per cent of long-duration space travellers experience lightheadness during re-entry or after landing.

### MUSCLE AND BONE LOSS
After six months in space, an astronaut's osteoporosis symptoms can be compared to those in elderly women on Earth, though there is large individual variability.



MALE

# HOW IS WATER FORMING ON THE MOON?

**Scientists have made a breakthrough discovery to explain the origin of water ice. Could water on the lunar surface be forming due to high-energy electrons from Earth?**

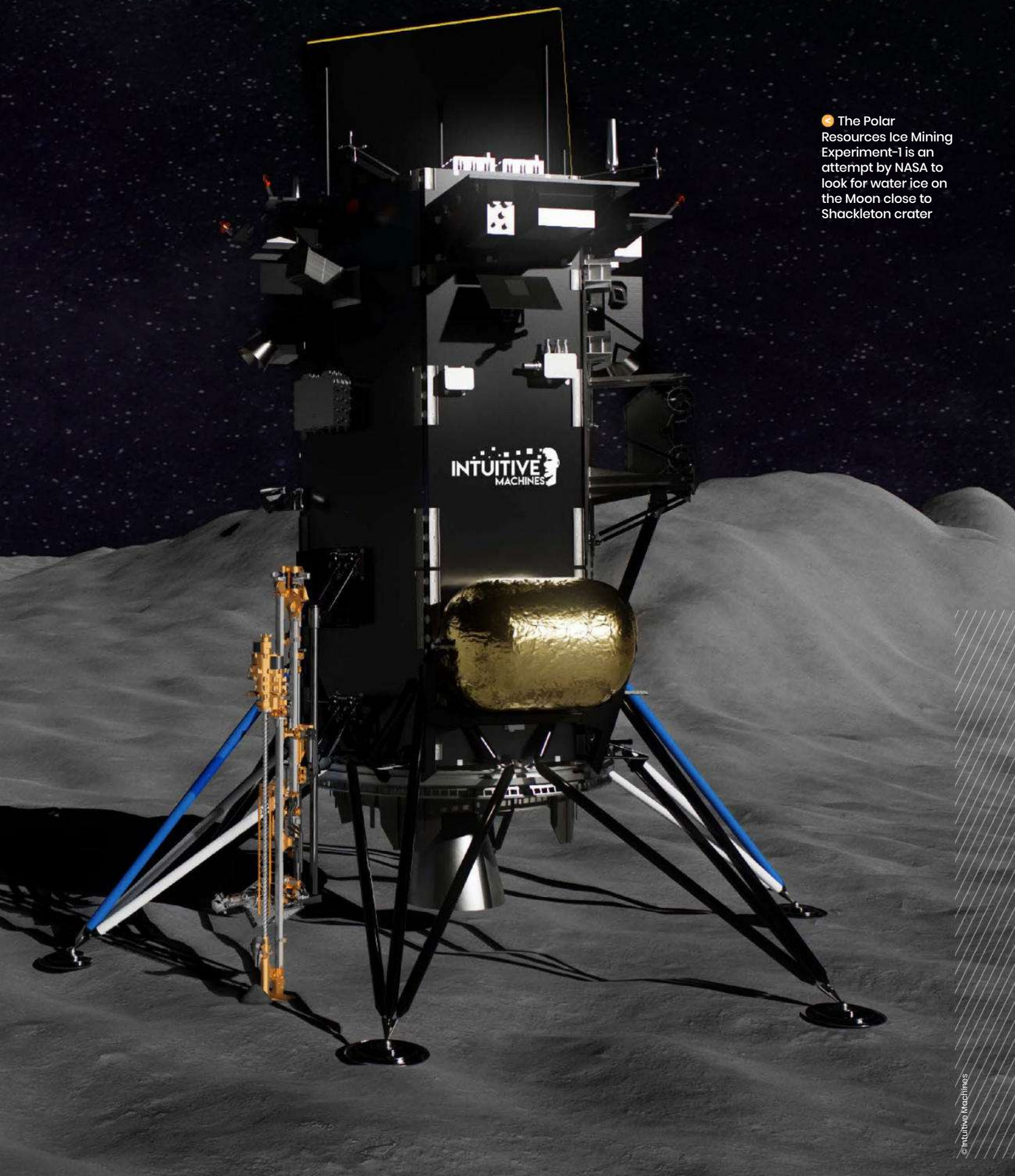
Reported by David Crookes

For decades, scientists have suspected that water ice exists on Earth's Moon. Water is also known to be widely distributed – not just present in the permanently shadowed areas of our natural satellite, but in the sunlit parts too, as confirmed by NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) in 2020, which noted molecular water trapped in regolith grains. Granted, the amount of water is small – there's actually 100 times more water in the Sahara Desert than there is in lunar soil. But that doesn't make its presence any less significant. The fact it's there at all is important enough.

The big question is how it came to be there. Could the water have been carried by comets and asteroids? Was it shared by Earth? Scientists have spent years trying to figure out this mystery, but now it seems as if they could be closer than ever. Shaui Li is a planetary scientist at the University of Hawaii at Mānoa. He became interested in working out where water on the Moon could have come from when he was in graduate school in 2011. This was at a time when data from the Moon Mineralogy Mapper imaging spectrometer on board India's first mission to the Moon, Chandrayaan-1, was well-calibrated and available.

"Whether and how much water exists on the lunar surface and where it has come from is a question that has been asked many times over in the lunar community," he tells **All About Space**. "The debate continued even after the return of Apollo lunar samples because most of them were exposed to the atmosphere, which led scientists to suspect that the observed water in the Apollo samples was sourced from Earth. At the time I started graduate school, the Moon Mineralogy Mapper data was just available, and that dataset was the only one scientists could use to study lunar surface water." It's this information, gathered between 2008 and 2009, which has been leading Li to an exciting theory, because it includes data collected when the Moon traversed through Earth's magnetotail – an area which, he says, effectively forms a natural laboratory for studying the formation processes of lunar surface water.

Finding water ice on the Moon is extremely challenging, which is why direct detection of surface water ice was only successful a few years ago. Li was




The Polar Resources Ice Mining Experiment-1 is an attempt by NASA to look for water ice on the Moon close to Shackleton crater

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## WATER ON THE MOON

**TWO**
The two poles of the Moon have permanently shadowed regions

**600**
There's more than 600 billion kilograms of water ice at the poles

**1645**
The presence of water on the Moon has been hypothesised for many centuries

**2009**
India's first lunar mission found water on the Moon

**100**
The Moon is 100 times drier than the Sahara Desert

**2013**
In 2013, water was found in samples from Apollo 15, 16 and 17

**Trillions**
Scientists believe trillions of pounds of water is trapped in tiny glass beads

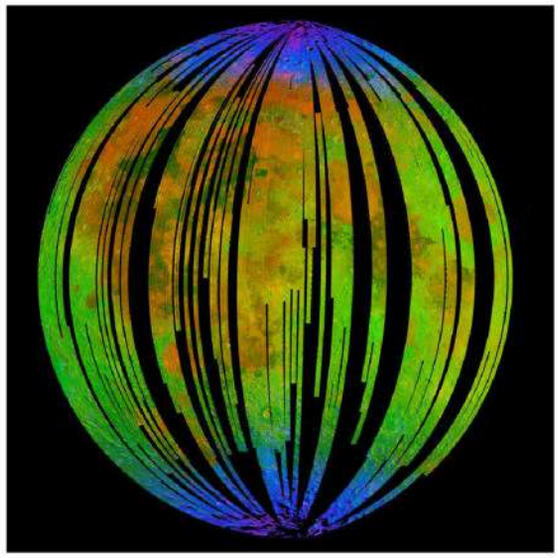
**2023**
The first map of Moon water was completed in 2023

at the forefront of this particular discovery in 2018, leading a study which found surface-exposed water ice in the lunar polar regions, as well as an abundance and distribution distinct from other airless bodies in the inner Solar System such as Mercury and Ceres.

"There have been a few challenges," Li explains. "First and foremost is that the water ice content on the lunar surface and shallow subsurface is extremely low. So while radar is a powerful tool for detecting water ice on many planetary bodies, such as Mercury, when the water ice content is low, the dielectric constants of the ice regolith mixtures cannot be significantly modified, and thus it cannot show anomalous signals in the radar data." As such, a lot of studies have sought indirect ways to detect water ice. "For instance, the neutron technique can detect any hydrogen-bearing species, including water ice," Li continues. "But when we see strong neutron data anomalies, it's difficult for us to tell whether they are water ice or hydroxide-bearing materials, dihydrogen or even hydrogen."

The hunt for water ice has been made all the more difficult because it's hard to clearly see and analyse certain parts of the Moon. "Near-infrared reflectance spectroscopy is currently the most efficient and direct way to detect low contents of water ice, but it's super challenging to use in the permanently shaded regions on the Moon where water ice is possibly harboured the most," Li adds. "This is because reflectance spectroscopy relies on sunlight as the light source and there's no direct sunlight in the permanently shaded regions. Since there's no atmosphere on the Moon, the scattered light from rough topography is the only light source to the permanently shaded regions, and it's super weak – less than one per cent than the sunlit surface."

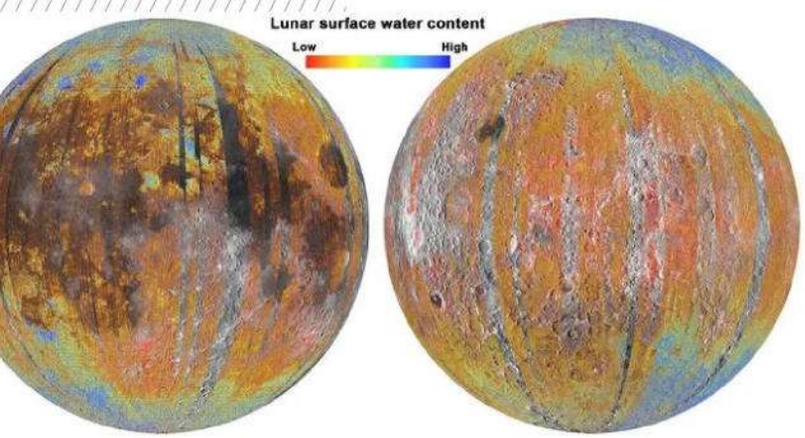
Add a low water ice content to the mix and you can see why it's been extremely difficult to detect water by using remote-sensing technologies. "It has been impossible to tell its origins before definitive detections of water ice," Li affirms. And that's why this mystery has been taking so long to resolve. To reach a conclusion, Li has been on something of an academic journey, making breakthroughs many times over. In 2020 he led a study which discovered the oxidised iron mineral hematite at high latitudes on the Moon. Since the Moon is virtually devoid of oxygen, this was unexpected.



This has led Li to believe that lunar surface iron is being oxidated by oxygen from Earth's upper atmosphere travelling via the magnetotail. Such weathering then led Li to investigate the Moon's passing through this area in much more detail. To better explain, the magnetotail is an elongated part of the magnetic bubble which surrounds our planet, shielding it from high-energy particles delivered from the Sun in the solar wind while allowing the Sun's light photons to pass. The magnetotail extends beyond the orbit of the Moon, and the celestial body orbits through it once every month.

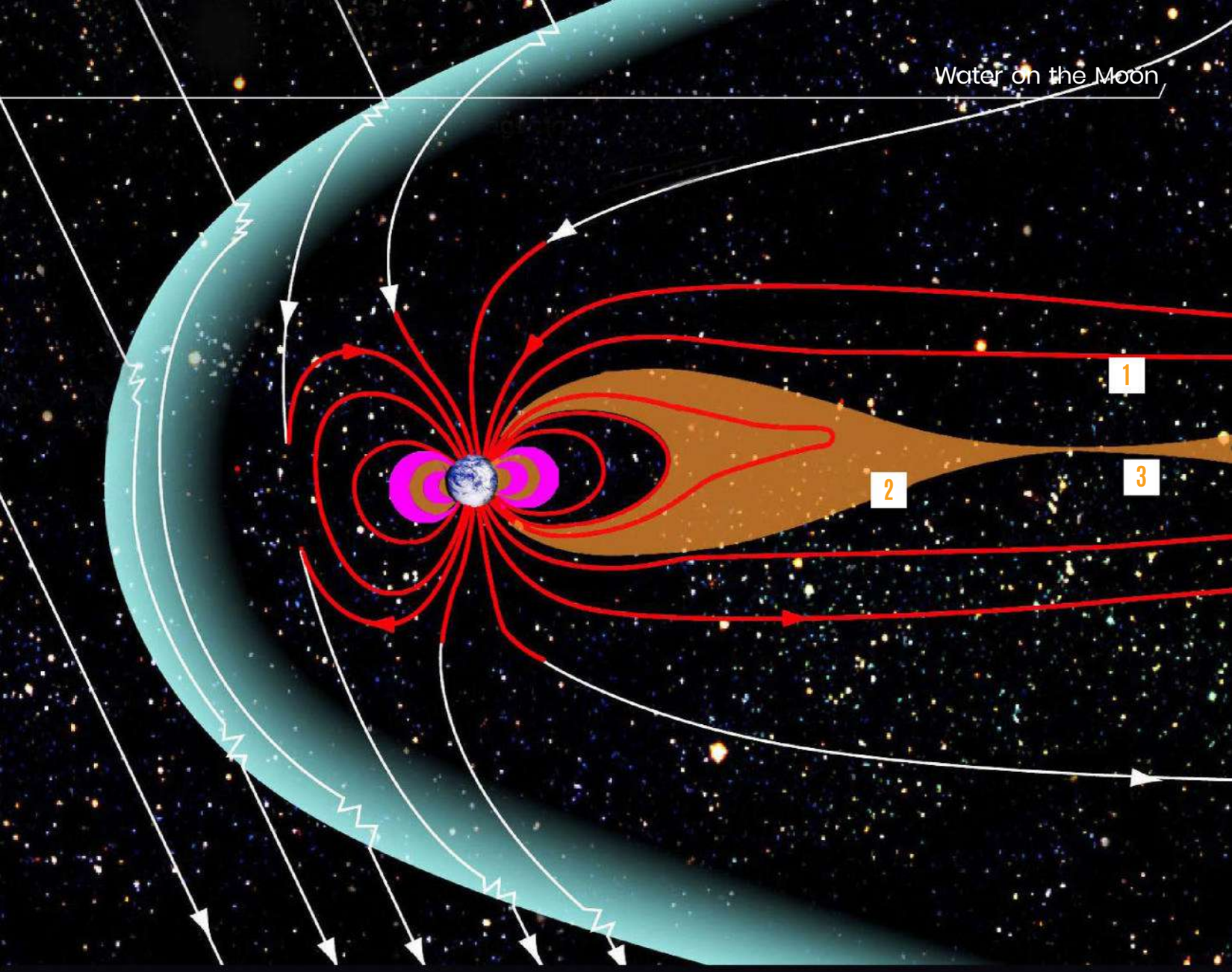
With no solar wind in the magnetotail, there are no solar wind protons, although there are high-energy electrons and ions forming a plasma sheet. In theory, a lack of solar wind should have meant no water could be formed whenever the Moon was within the magnetotail. But as Li discovered, that was not the case. Water formation on the lunar surface was almost identical regardless of whether the Moon was inside or outside Earth's magnetotail. "I was surprised and double-checked it several times," Li says. "Then I realised that there should be some unrecognised processes about water formation on the Moon when the solar wind is shut off."

It suggests that the solar wind cannot be the only explanation for the presence of water on the Moon – a twist in the tale which has been getting scientists very excited. "Our understanding about the origin of lunar surface water has been drastically improved in the last decade through remote-sensing observations, laboratory simulations of solar wind radiation and




The Moon Mineralogy Mapper confirmed water locked in minerals on the Moon, shown here in blue

This shows how water is distributed on the near and far side of the Moon




# HOW THE MOON ENCOUNTERS EARTH'S MAGNETOTAIL

**The Moon travels right through this part of our planet's magnetosphere**

### 1 Creating the magnetotail

The magnetosphere is an area around our planet that is dominated by its magnetic field. It protects Earth from harmful levels of radiation from the Sun. When the solar wind collides with the magnetosphere, it's deflected around the planet. This forms a lengthy tail.

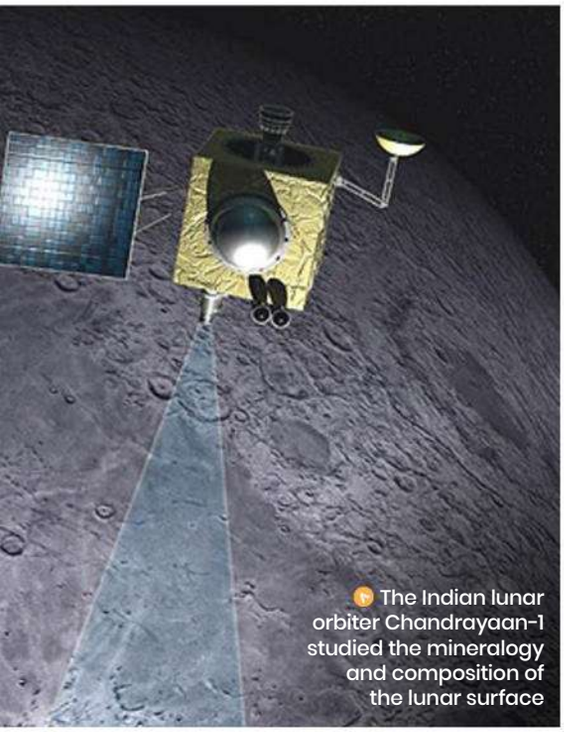
### 2 The plasma sheet

Trapped inside the magnetotail, which is about 1,000 times Earth's radius, is the plasma sheet. It contains hot charged particles, including electrons. There are almost no solar wind protons inside the magnetotail.

### 3 Orbiting Moon

The Moon travels through the magnetotail and its plasma sheet. At this stage, it's protected from the solar wind. Since water is still formed on the lunar surface within the magnetotail, it points to the possibility of new sources of water or formation processes.

© NASA/Goddard/Aaron Kaase



The Indian lunar orbiter Chandrayaan-1 studied the mineralogy and composition of the lunar surface

© ISRO

## WHERE DID THE MOON GET ITS WATER FROM?

**There are a number of theories explaining the presence of water on the Moon**

### Water was transported by comets

Scientists already believe that much of the water on Earth was carried by comets and asteroids colliding with the planet's surface. The same could also be true of the Moon – and the two bodies may even have received water at the same time. The Moon could have been a water-strewn chunk of Earth that broke away billions of years ago.

### Water is produced by the solar wind

Small amounts of water can be found outside of the polar regions, and the Sun may be playing a big part in this. Oxygen atoms are bound in rocks and particles on the surface of the Moon, and their chemical bonds may be broken by the solar wind, which carries hydrogen. Two hydrogen atoms and a single oxygen atom create water.

### Electrons are playing a part

The latest study by the University of Hawaii at Mānoa has found that water forms even when the Moon is protected from solar wind photons at the point when the Moon passes through the Earth's magnetotail. This points to the potential for high-energy electrons in a plasma sheet within the magnetotail playing a part in water formation on the lunar surface.

theoretical modelling," Li explains. "The community believes that implantation of solar wind protons should be one of the major processes inducing water on the lunar surface.

"The Moon's passage through Earth's magnetotail drew my attention after I made the first global water map of the Moon in 2017 because it's well known, and has been measured, that solar wind protons can be almost completely shielded in the magnetotail. If implantation of solar wind protons is a major process inducing water on the lunar surface, it's predicted no water formation in the magnetotail due to the shielding of solar wind protons. After I formulated this hypothesis, I started to process the data, and I expected to see no water formation in the magnetotail. When I saw the data analysis results showing no water content change in the magnetotail, I was totally surprised. There must be unrecognised processes going on that are different from a typical implantation of solar wind protons."

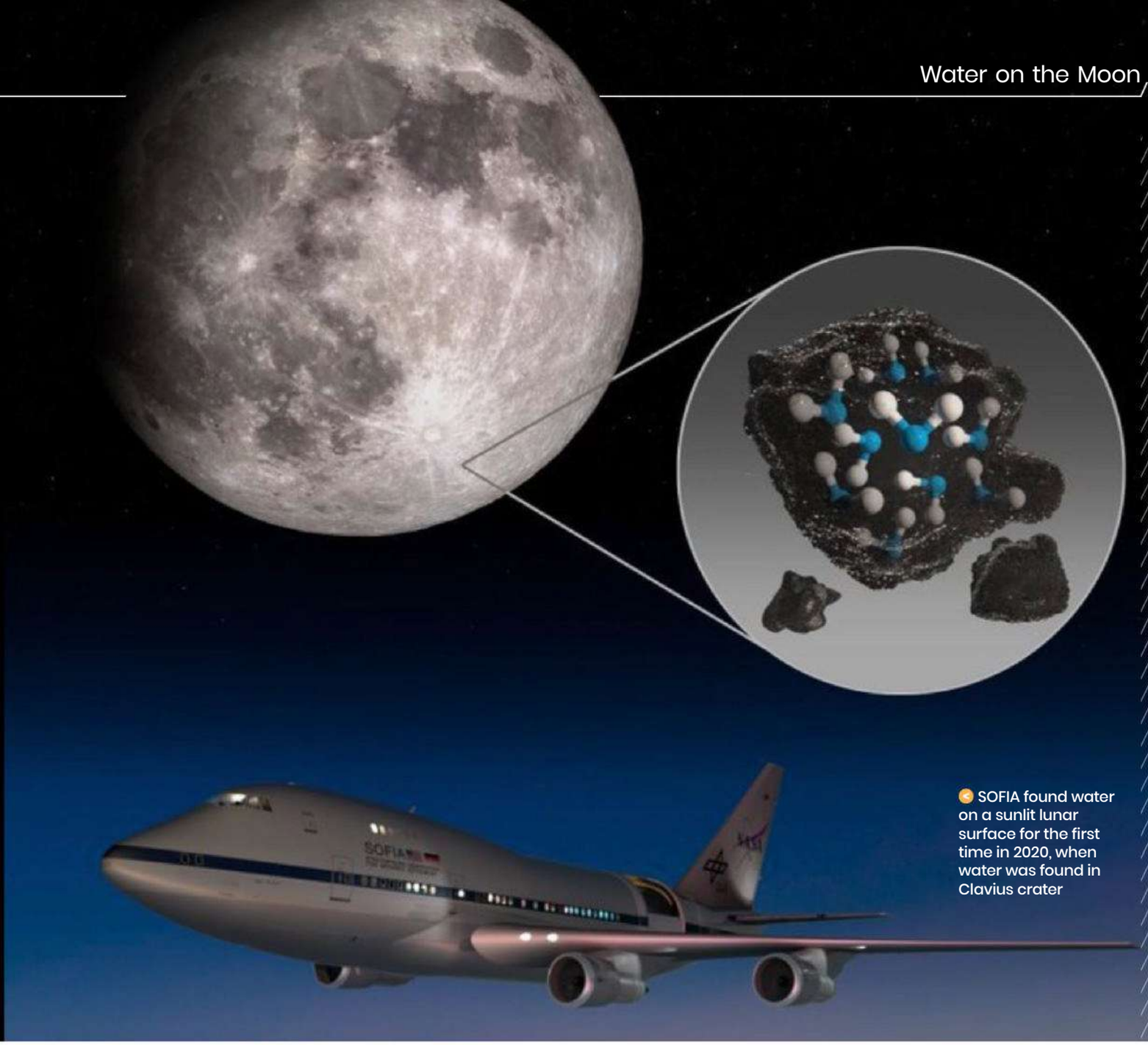
Working out what those processes could be quickly occupied Li's mind. The high-energy electrons within the plasma sheet that resides within the magnetosphere through which the Moon travels could, Li surmised, not only be contributing to the weathering processes on the lunar surface, but aiding the formation of water, too. "Our theory about lunar surface water formation by solar wind implantation predicts no water formation in the magnetotail," Li affirms. "However, the remote-sensing observation shows a similar water formation rate in the magnetotail which is completely contradictory to the hypothesis. Then I realised that there should be unrecognised processes about water formation in the magnetotail not due to the implantation of solar wind protons."

All of this points to the water on the Moon being very closely tied to Earth. "The solar wind protons do not directly help water formation in the magnetotail," Li affirms. But that isn't to say that the solar wind isn't having any effect at all. "We believe that the hydrogen source in the water formation process in the magnetotail should be from solar wind," Li says. "Earth's magnetic field is the force that is accelerating electrons in the plasma sheet, and we know the plasma sheet connects to Earth. But the sources of electrons in the plasma sheet are not completely clear. Studies suggest that electrons could be from both Earth and solar wind."

Such findings are significant. It explains how water ice can gather on the surface in permanently shaded regions, and the information will be useful for future crewed missions to the Moon, shedding light on where water ice can be concentrated and distributed. "It may help explain the surface

Shackleton crater is in a permanently shadowed region of the Moon

© Jorge Mañes Rubio. Spatial design & visualisation in collaboration with DITISHOE http://ditishoe.co: ISRO



SOFIA found water on a sunlit lunar surface for the first time in 2020, when water was found in Clavius crater

water ice observed in the permanently shaded regions where sunlight cannot directly reach; these are regions where the high-energy electrons in the plasma sheet can reach," affirms Li. "Electrons also travel in random directions in the plasma sheet, and the plasma sheet is much bigger than the Moon."

The next step is to track the Moon as it travels through to the magnetotail so that the team can investigate the plasma environment and water content at the lunar poles during the passage – something Li is going to be doing as part of NASA's Artemis program. "We will need ground observations of the plasma environment and the water content variation both on the sunlit surface on the lunar nearside and in permanently shadowed craters on both the near and far side," Li says.

This could also help explain how water could be present on other celestial bodies, and that in turn could also assist in the wider hunt for life. "High-energy electrons from a solar storm can reach all airless body surfaces in the Solar System, which means that they can contribute to water formation," Li explains. "And this not only applies to the Solar System, but also applies to the universe, where water can be formed by high-energy electrons in conjunction with protons and oxygen-bearing materials."

As such, the team's research, which was published in the journal *Nature Astronomy*, could prove pivotal, showing how water is distributed throughout our Solar System. With crews set to visit the Moon aboard Artemis III in 2025, it's also rather well timed. Learning more about water on the Moon could eventually pave the way for many more discoveries in the wider Solar System and beyond.

**David Crookes**
*Science and technology journalist*
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

FOCUS ON

# NASA SEEKS CITIZEN SCIENTISTS TO CAPTURE THE APRIL 2024 TOTAL SOLAR ECLIPSE

## If you're in the path of totality, you can contribute to research about the Sun

Reported by Sharmila Kuthunur

Observers who plan to watch the total solar eclipse in April next year can use a new NASA-funded app to record valuable data about the Sun. Using a free app from SunSketcher, citizen scientists can help advance heliophysics research by capturing as many images of the Sun as possible just before and after the solar eclipse. Those images will help in recording data on a bright, broken ring of sunlight known as Baily's beads, which shines through mountains and valleys on the edge of the Moon just before and after eclipses."There are so many ways to participate in NASA science, especially as we enter the Heliophysics Big Year," space physicist Elizabeth MacDonald, the heliophysics citizen science lead at NASA, said. "We're so excited to watch these and our many other projects come to life."

SunSketcher's app is being developed by a team of students and professors at Western Kentucky University (WKU) and is the newest of five projects to receive funding from NASA this year to collect science data from the next total solar eclipse. "Our goal is to get a bunch of people – millions of people, hopefully – in the path of the eclipse to use our app and get a few pictures of the Sun as the eclipse happens and as the eclipse ends," Starr May, a computer science major at WKU working on the app, said.

The SunSketcher app is an improved version of an app used for a similar purpose during the total solar eclipse in August 2017. The new app will use the GPS coordinates of smartphones to track precisely when the Baily's beads phenomenon will begin and end locally across the path of totality, which is where the Moon's shadow will fall on Earth during the eclipse. Totality begins in 12 US states: Oklahoma, Arkansas, Missouri, Illinois, Kentucky, Indiana, Ohio, Pennsylvania, New York, Vermont, New Hampshire and Maine.

Pictures from all the observations will ultimately be combined into an hour-long 'megamovie' to better understand the Sun's shape by using the Moon as a reference. Specifically, the observations will reveal how much the Sun deviates from being a perfect sphere. "This information will lead to an improved understanding of the flows in the solar interior, and is also key to testing gravitational theories," NASA representatives said.

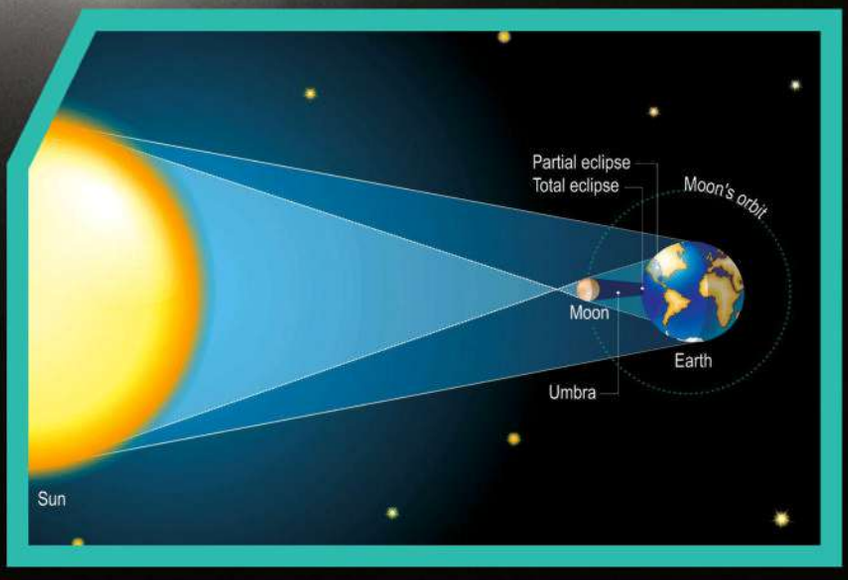
Other citizen science projects being funded by the space agency include an experiment to study the structure of the solar wind and the corona, the outermost part of the Sun's atmosphere, which has long puzzled scientists by being at least a thousand times

> "Our goal is to get a bunch of people – millions of people, hopefully – in the path of the eclipse to use our app and get a few pictures of the Sun"
>
> **Starr May**

The Sun and Moon appear a similar size in the sky when viewed from Earth

hotter than the surface of the Sun. NASA has also planned a second megamovie to record the thin layer underneath the corona, known as the chromosphere. The megamovie will be the end result of an image-processing competition for volunteer photographers and data analysts, with a goal to unveil jets of plasma in images captured during the 2024 eclipse.

The Sun is steadily growing more active as it nears its predicted peak in activity in 2025 – known as solar maximum – so the eclipse in April next year will likely capture more activity on the Sun compared to the 2017 total solar eclipse.

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ASTROPHYSICS

# How does the interstellar medium help form stars?

The material which fills the space between stars provides the raw materials for new stars to be born. It's mostly hydrogen, some helium and a tiny amount of dust particles. Within the interstellar medium, there are clouds of varying densities that are rich in molecules like hydrogen and carbon monoxide. These molecular-rich gas and dust clouds provide the ingredients that ultimately make up the building blocks of stars. In the densest regions of the interstellar medium, the core collapse of such a cloud can be triggered by a shock wave. These shock waves can be caused by a nearby supernova, by a collision with another molecular cloud or even by passing through the spiral arm of a galaxy, like our Milky Way. Such a shock wave can cause the rapid infall of the molecular material to produce the core of a new star, which continues to accrete as the star is born. These regions in the interstellar medium are stellar nurseries in the cosmos and are critical to the cycle of the life of a star.

**Dr Emily Rickman, research fellow in astronomy at the European Space Agency**

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Stars form from clouds of gas and dust under pressure

Plants can be grown in space as a food source

Gold is used to protect the eyes of astronauts from radiation

SPACE EXPLORATION

## How important is astrobotany research for future space exploration efforts?

Astrobotany is going to be critical for future space exploration, particularly in the realm of providing caloric support for extended spaceflight missions. In the near future, it's unlikely we will use plants as an oxygen source in a bioregenerative life-support system because gas exchange is more easily controlled manually than relying on plants to produce enough oxygen to support a crew. The science is not precise or reliable enough to depend on just plants for oxygen. However, it will be of huge benefit to supplement caloric intake with plants in space. The sustainability of harvesting in space is another perk that cannot go overlooked. Resupplies to the International Space Station (ISS) are necessary, but resupplies beyond the relatively short distance to the ISS could become impossible, or not time or cost effective. Future missions will need to rely on sustainable plant growth to supplement caloric intake, and the added benefit is that it's supposed to be an immense help for astronauts' mental health.

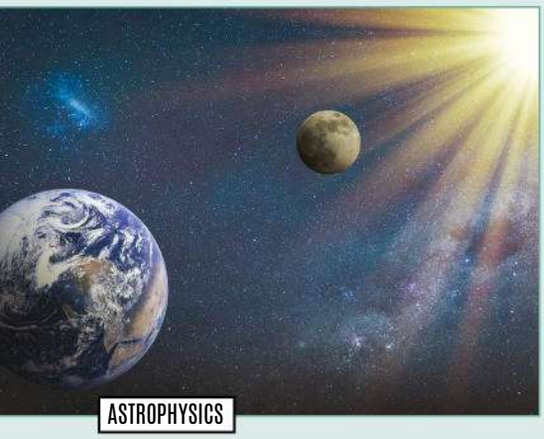
**Kai Rasmussen, analytical scientist and director of astrobotany.com**

SPACE EXPLORATION

## Why is there gold on an astronaut's visor?

Gold has a variety of properties which make it an extremely useful material when designing objects to go into space. It is very reflective of infrared radiation – a vital consideration for protecting astronauts' eyes – hence the thin layer of gold in their visors. Infrared isn't the only harmful type of radiation that visors need to protect against, though. There's another thin layer specifically for reflecting ultraviolet radiation that is very similar to sunglasses used down here on Earth. Gold is also important in many other objects destined for space; many satellites are partially covered in gold-coated sheets. These sheets keep the satellites cool by reflecting infrared radiation away from the spacecraft and minimising any absorption of this heat. Gold also doesn't tarnish or rust at the same rate as lots of other metallic options, therefore needing less time and expense to maintain during missions.

**Megan Whewell, former presenter at the National Space Centre**



ASTROPHYSICS

## If Earth were orbiting a star in the central hub of the galaxy, would we experience permanent daylight?

It was initially thought that the gravitational forces and interactions between the large numbers of stars at the galactic centre would make it impossible for planets to form in stable orbits. But research is suggesting this might not be the case. So what would life be like on one of these planets? The first major problem is that planets in the centre of the galaxy would be bathed in harmful radiation, effectively sterilising them. Harmful gamma rays, X-rays and cosmic rays would bombard the planet, killing any life that potentially developed. As to whether or not there would be permanent daylight, it all depends how close the stars are. There are definitely more stars squashed into smaller spaces, but it's still thought that at least a light year separates all the stars. On Earth our nearest neighbour, Proxima Centauri, lies four light years away and appears as a faint dot. This star wouldn't appear much brighter if it was only a light year away. While the sky would certainly be more densely packed, it's doubtful you'd experience permanent daylight. Of course, with a much greater density of stars you increase your chance of being in a binary star system, which would certainly have a large effect on the day and night cycle.

**Josh Barker, education and outreach officer at Space Park Leicester**

SPACE EXPLORATION

## How do you navigate a spacecraft?

Navigation consists of two parts: determining the current location and heading and defining how to reach the target. This applies to cars, planes and ships as well as spacecraft. For a spacecraft, determining the location and heading, such as the orbital state, requires a radio link from the spacecraft to ground stations on Earth. This tells us the current distance because we can see the signal travel time. We also see the Doppler shift, a change in the received frequency depending on the speed at which the spacecraft travels towards or away from Earth. We need a lot of measurements that cover a time span of days or weeks. A very complex, repetitive mathematical procedure on a computer then finds out the one set of orbital elements at a given time, which reproduces the set of measurements obtained.

In theory, once the orbital state is known, the state can be computed at any later time. But in practice this doesn't work out because the state is never known perfectly. Also, the orbit is perturbed by factors that we don't know exactly. Our prediction and the actual orbit will drift apart, and the above process must be repeated regularly. Getting to the target requires correction manoeuvres using small rocket engines on the spacecraft. These manoeuvres can be computed and applied every time the orbital state has been updated.

**Michael Khan, engineer at the European Space Agency**

Many parameters must be studied when guiding a spacecraft

The centre of the galaxy is filled with harsh radiation

Sometimes chunks of Mars fall to Earth

SOLAR SYSTEM

## What do Martian meteorites tell us about the Red Planet?

Meteorites from Mars tell us about the geology and history of the Red Planet without the cost of a space mission. Clues that they come from Mars include that they are young and formed from lava, something difficult to explain if they had originated from the asteroid belt. These rocks have been ejected from Mars by violet impacts of asteroids or comets. The impact and ejection process forms glass that contains captured gas with a chemistry identical to the atmosphere of Mars, as measured by the Viking landers in the 1970s. Radiation-based evidence of the timing of ejection, alongside similarities between some samples, reveal that there are groups of Martian meteorites, with each group related to an individual impact event. Martian meteorites have allowed us to optimise techniques for use on landers and rovers on the surface of Mars and in laboratories back on Earth. These naturally delivered and highly valuable samples are helping us prepare for Mars sample return.

**Mark Sephton, professor of organic geochemistry at Imperial College London**

ASTROPHYSICS

# Why are there no green stars?

The night sky is speckled with colour. Although most stars appear white, you will see others that are yellow, orange, red or even blue, but you will never see a star that is green. Why is that? Stars whose peak wavelength is in green – with a wavelength of 550 nanometres – have a surface temperature of 5,300 Kelvin, which is just a bit less than the Sun, so there are plenty of these objects. But I think the lack of green stars is a matter of human physiology, not astronomy. Our retinae do have a cone sensitive to green, but there is only a narrow band of wavelengths in which it predominates. For wavelengths a bit shorter, we see blue, while for slightly longer wavelengths we see either yellow or red. The reason why we don't see any green stars is because of the way humans perceive visible light.

**Steven W. Stahler, physics lecturer and research astrophysicist at the University of California, Berkeley**

© Alamy, Getty, NASA

FOCUS ON

# WEBB SNAPS THE MOST DISTANT GRAVITATIONALLY LENSED OBJECT EVER SEEN

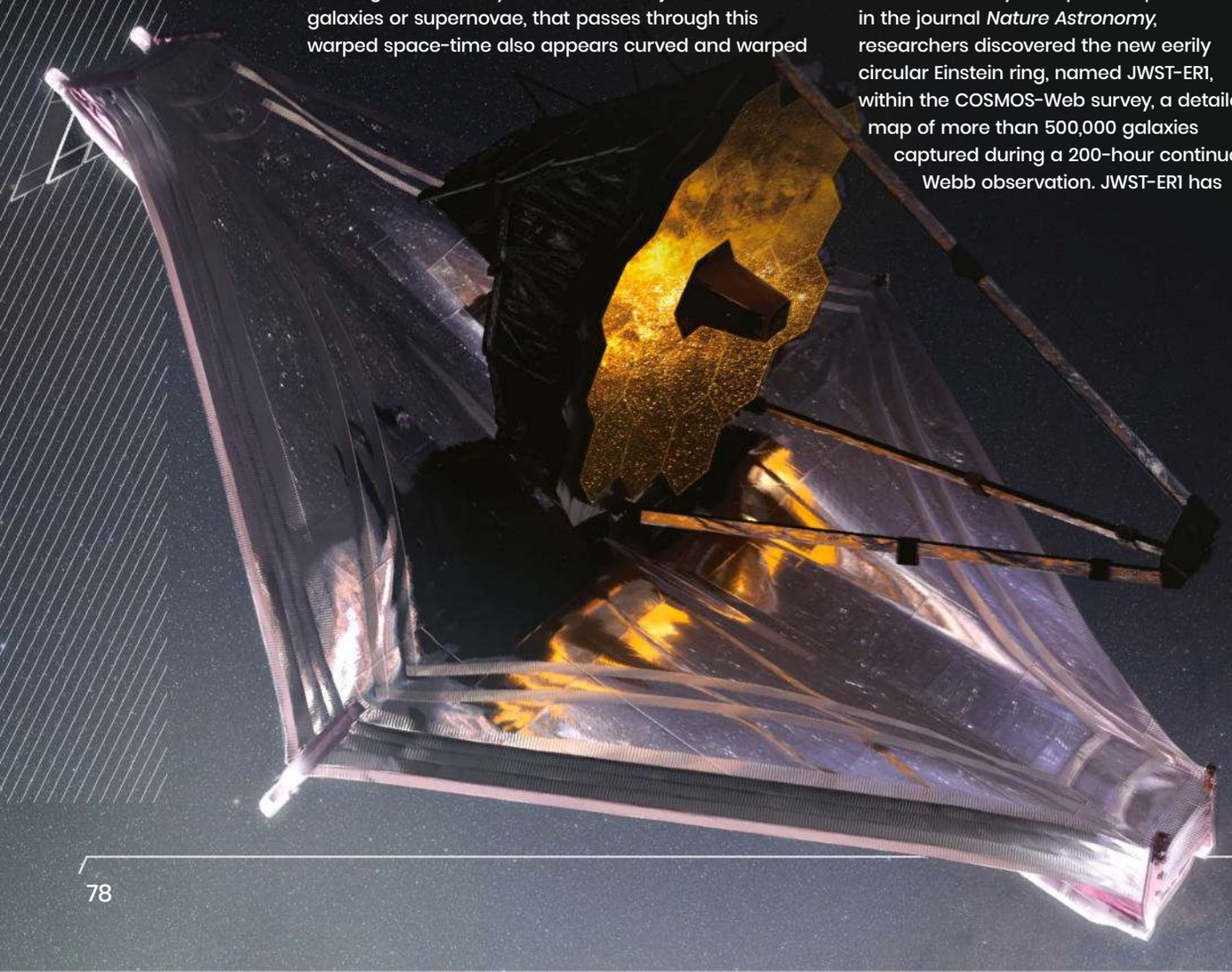
## The stunning image reveals a perfectly formed Einstein ring

Reported by Harry Baker

Photos snapped by the James Webb Space Telescope have revealed the farthest ever example of an Einstein ring. The record-breaking halo of warped light, which is a whopping 21 billion light years away, is unusually perfect and surrounds a mysteriously dense galaxy. An Einstein ring is an extremely rare type of gravitationally lensed object that was first predicted by Albert Einstein's theory of relativity.

Gravitational lensing occurs when the immense gravity of a massive foreground object, such as a galaxy cluster or black hole, warps space-time around itself; light emitted by more distant objects, such as galaxies or supernovae, that passes through this warped space-time also appears curved and warped from our perspective on Earth. This effect also magnifies the light of the object being lensed, similar to how a magnifying glass works, allowing astronomers to study distant objects in greater detail than is normally possible. Most gravitationally lensed objects form arcs or partial rings that surround the foreground object. But a true Einstein ring forms a complete circle around the closer entity, possible only when the distant object, foreground object and observer are perfectly aligned.

In a new study accepted for publication in the journal *Nature Astronomy*, researchers discovered the new eerily circular Einstein ring, named JWST-ER1, within the COSMOS-Web survey, a detailed map of more than 500,000 galaxies captured during a 200-hour continuous Webb observation. JWST-ER1 has



two parts: JWST-ER1g – the compact galaxy that acts as the lensing object in the foreground – and JWST-ER1r, the light from a more distant galaxy that forms the luminous ring. The galaxy JWST-ER1g is located around 17 billion light years from Earth, while JWST-ER1r is another 4 billion light years away. Until now, the farthest detected lensing object was around 14.7 billion light years away. While the age of the universe itself is estimated to be about 13.8 billion years, the universe's constant expansion means that light from the oldest objects must travel much farther than this to reach our telescopes.

Thanks to the complete ring of JWST-ER1, researchers calculated the mass of the lensing galaxy by seeing how much it had warped space-time around itself. This revealed that the galaxy has a mass equivalent to around 650 billion Suns, making it unusually dense for its size. Some of this extra mass can be explained by dark matter, the mysterious invisible matter that makes up around 85 per cent of all matter in the universe. But even then it's unlikely that there are enough stars to account for the rest of the galaxy's heft based on the researchers' calculations. "Additional mass is needed to explain the lensing results," but it's not exactly clear what this mass is, the researchers wrote.

Other similarly old and equally dense galaxies have been detected before, which suggests there is something common about these ancient star factories that makes them so massive. One explanation is that these galaxies harbour much more dark matter than expected, while another theory suggests that they may have more small-mass stars lurking within them than younger galaxies do. But more work is needed to find out.

This isn't the first true Einstein ring spotted by Webb. In September 2022, a Reddit user discovered a perfectly circular ring of light from the galaxy JO418, located around 12 billion light years from Earth, lensed around a closer galaxy. Webb has also utilised gravitational lensing to snap the most distant star ever detected and one of the universe's oldest galaxies.

In the field of one of Webb's largest area surveys, COSMOS-Web, an Einstein ring was discovered around a distant galaxy

## MASSIVE COSMIC LENS

**1 Galaxy**
The light from distant galaxies can be seen from Earth, but the pictures that we capture don't always match what's really there thanks to gravitational lensing.

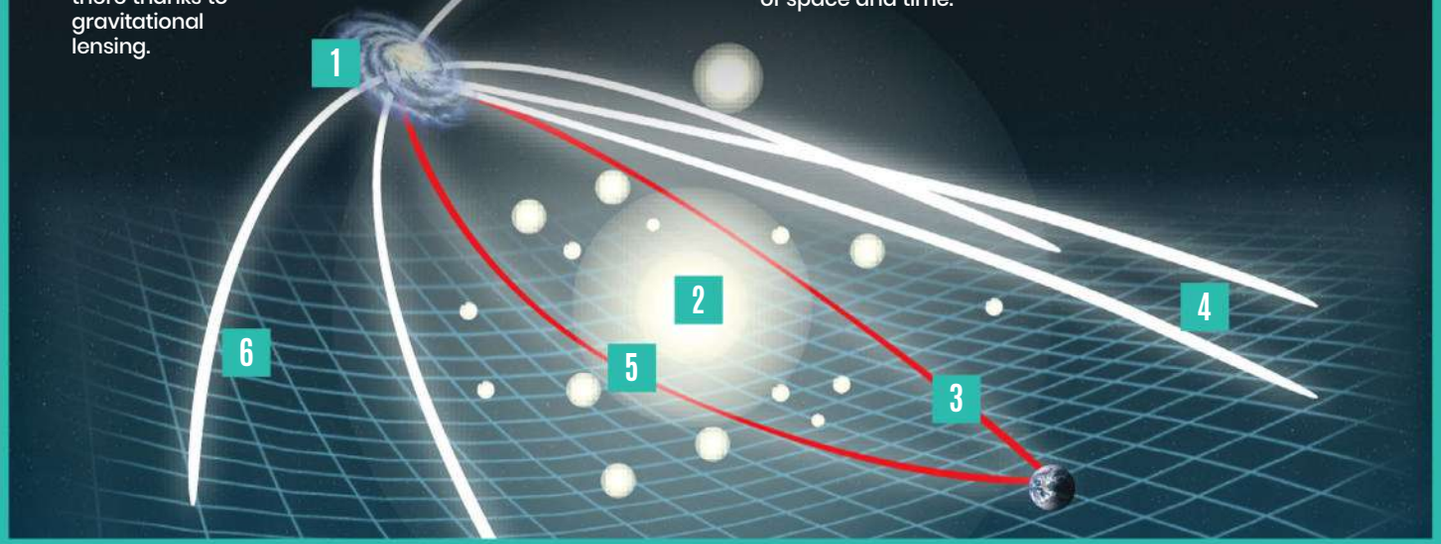
**2 Galaxy cluster**
This massive cluster of galaxies between Earth and the distant galaxy has created an enormous curve in the fabric of space-time.

**3 Path bent**
The photons of light released by the distant galaxy curve their paths as they travel past the massive cluster of galaxies.

**4 Space-time**
This two-dimensional representation of space-time gives an idea of what's really happening in the four dimensions of space and time.

**5 Lensed image**
The path of the light is bent so much that the image appears more than once in the sky, either as a duplicate or as streaks or rings.

**6 Cosmic magnification**
This phenomenon is known as gravitational lensing because the curve in space-time bends light.

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# WHAT'S IN THE SKY?

**What to look out for during this observing period**

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**87 Naked eye and binocular targets** The night sky is rich in pretty star clusters and bright, colourful stars

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**3 NOVEMBER**
Jupiter is at opposition in Aries, dazzling at -2.9

**4 NOVEMBER**
Saturn will reach the end of its retrograde motion, ending its westward movement

**5 NOVEMBER**
Asteroid 18 Melpomene reaches opposition in Eridanus, glowing at magnitude +8.0

**9 NOVEMBER**
The Moon will pass in front of Venus, creating a lunar occultation

**12 NOVEMBER**
The Northern Taurid meteor shower reaches its peak

**13 NOVEMBER**
Uranus is at opposition in Aries, glowing at magnitude +5.6

**18 NOVEMBER**
The Pleiades star cluster (Messier 45) is well placed in Taurus

"The Moon will pass in front of Venus, creating a lunar occultation"

**21 NOVEMBER**
The Alpha Monocerotid meteor shower reaches its peak

**25 NOVEMBER**
The Moon and Jupiter make a close approach, within 2°31' of each other in Aries

**27 NOVEMBER**
The Moon and the Pleiades star cluster (Messier 45) pass within 1°00' of each other in Taurus

**28 NOVEMBER**
The Moon will pass in front of Beta Tauri, creating a lunar occultation

**28 NOVEMBER**
The November Orionid meteor shower reaches its peak

**28 NOVEMBER**
The Hyades star cluster (Collinder 50) is well placed in Taurus

Naked eye | Naked eye warning (TAKE CARE!) | Binoculars | Small telescope | Medium telescope | Large telescope | Solar eclipse | Solstice

## 9 NOVEMBER

The Moon and Venus make a close approach, within 53.1' of each other in Virgo

## 18 NOVEMBER

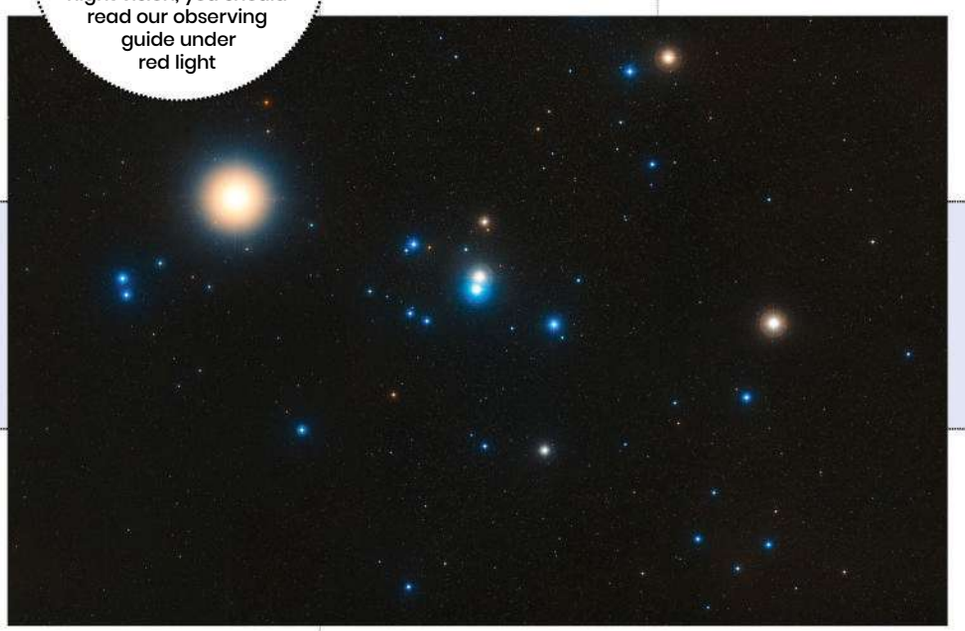
The Leonid meteor shower reaches its peak

## 20 NOVEMBER

The Moon and Saturn make a close approach, within 2°29' of each other in Aquarius

### Red-light friendly

In order to preserve your night vision, you should read our observing guide under red light



# Jargon buster

### Conjunction

An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

### Declination (Dec)

How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

### Opposition

When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

### Right Ascension (RA)

RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis we see different parts of the sky throughout the night.

### Magnitude

An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of -1.0 is brighter than +2.0.

### Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© Getty; NASA/ESA;

# PLANETARIUM

16 NOVEMBER 2023

OPPOSITION

EVENING SKY

## MOON CALENDAR

* The Moon does not pass the meridian on 27 November

| 2 NOV | 3 NOV | 4 NOV | 5 NOV |
|---|---|---|---|
| 79.5% | 70.6% | 61.0% | TQ 51.1% |
| 12:39 19:18 | 13:22 20:25 | 13:52 21:37 | 14:14 22:51 |

| 6 NOV | 7 NOV | 8 NOV | 9 NOV | 10 NOV | 11 NOV | 12 NOV |
|---|---|---|---|---|---|---|
| 41.4% | 32.0% | 23.3% | 15.6% | 9.0% | 4.0% | 1.0% |
| 14:30 22:51 | 00:03 14:42 | 01:14 14:53 | 02:25 15:03 | 03:36 15:13 | 04:49 15:24 | 06:06 15:38 |

| 13 NOV | 14 NOV | 15 NOV | 16 NOV | 17 NOV | 18 NOV | 19 NOV |
|---|---|---|---|---|---|---|
| NM 0.1% | 1.5% | 5.5% | 11.9% | 20.4% | 30.6% | 41.9% |
| 07:26 05:56 | 08:48 16:22 | 10:09 16:59 | 11:20 17:53 | 12:14 19:05 | 12:53 20:29 | 13:20 21:57 |

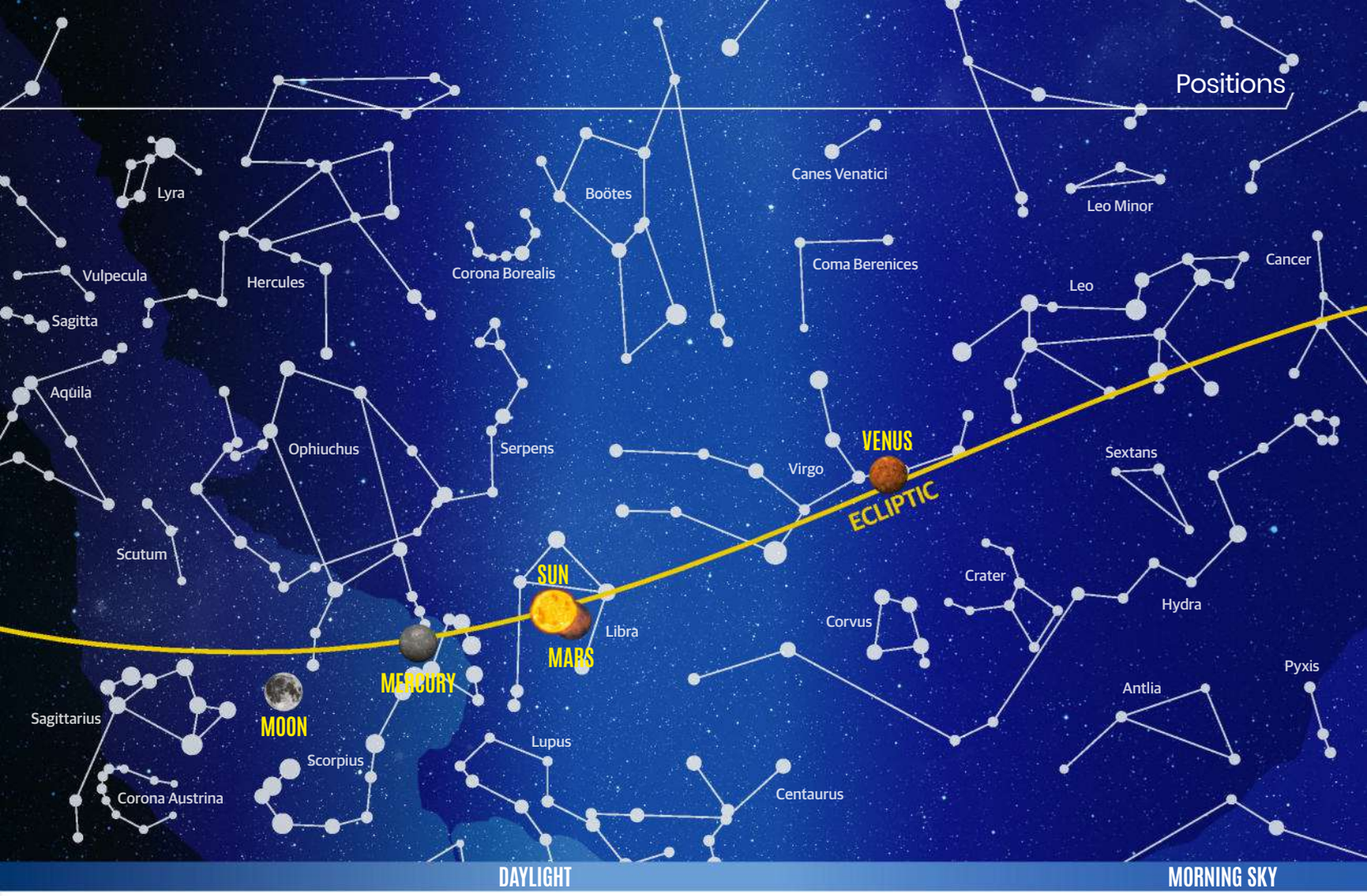
| 20 NOV | 21 NOV | 22 NOV | 23 NOV | 24 NOV | 25 NOV | 26 NOV |
|---|---|---|---|---|---|---|
| FQ 53.7% | 65.4% | 76.1% | 85.3% | 92.6% | 97.5% | 99.7% |
| 13:39 23:26 | 13:54 --:-- | 00:52 14:07 | 02:17 14:19 | 03:41 14:33 | 05:07 14:48 | 06:33 15:08 |

| 27 NOV | 28 NOV | 29 NOV | 30 NOV |
|---|---|---|---|
| FM --.-%* | 99.4% | 96.7% | 91.9% |
| 07:59 15:35 | 09:18 16:12 | 10:25 17:03 | 11:15 18:07 |

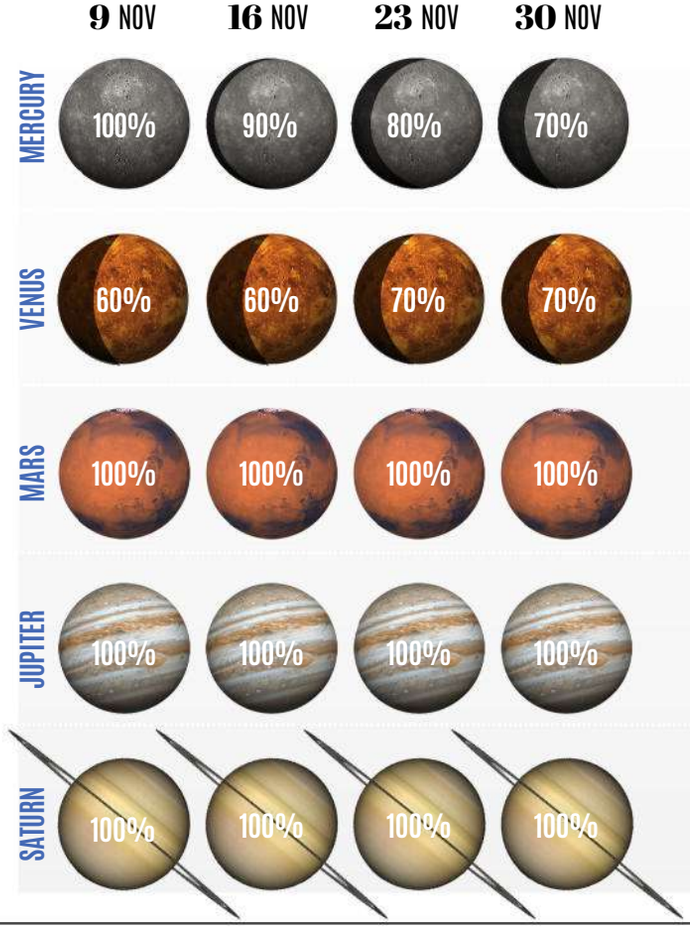
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)




# ILLUMINATION PERCENTAGE




# PLANET POSITIONS

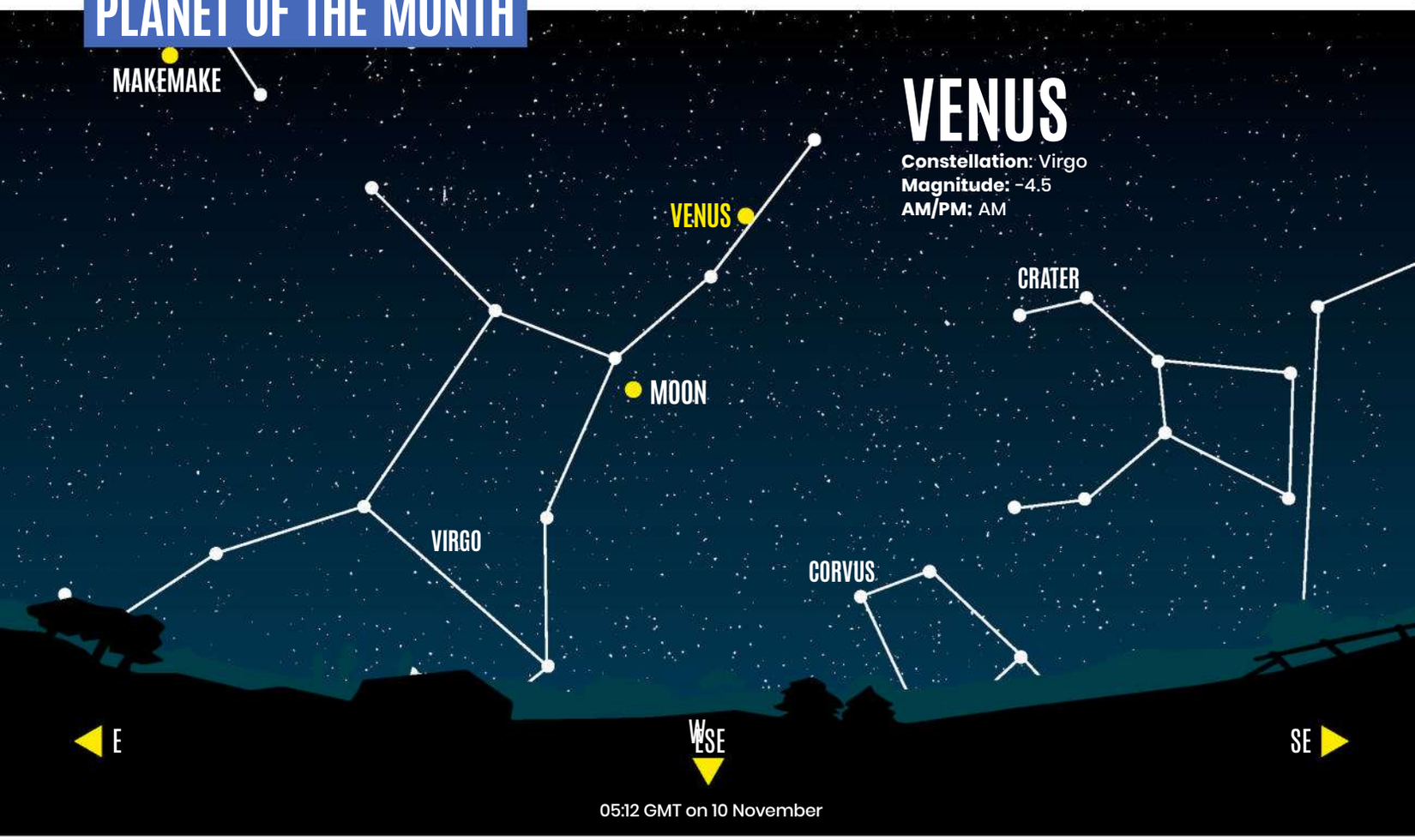
All rise and set times are given in GMT

| DATE | RA | DEC | CONSTELLATION | MAG | RISE | SET |
|---|---|---|---|---|---|---|
| 2 NOV | 15h 03m 20s | -18° 02' 29" | Libra | -0.7 | 07:43 | 16:42 |
| 9 NOV | 15h 46m 51s | -21° 24' 36" | Libra | -0.5 | 08:20 | 16:36 |
| 16 NOV | 16h 30m 52s | -23° 55' 13" | Ophiuchus | -0.4 | 08:55 | 16:35 |
| 23 NOV | 17h 14m 33s | -25° 26' 22" | Ophiuchus | -0.4 | 09:23 | 16:38 |
| 30 NOV | 17h 55m 18s | -25° 50' 59" | Sagittarius | -0.5 | 09:41 | 16:48 |
| 2 NOV | 11h 38m 41s | +03° 07' 57" | Virgo | -4.3 | 02:29 | 15:12 |
| 9 NOV | 12h 07m 13s | +00° 35' 42" | Virgo | -4.3 | 02:43 | 15:00 |
| 16 NOV | 12h 36m 23s | -02° 06' 49" | Virgo | -4.2 | 02:58 | 14:48 |
| 23 NOV | 13h 06m 12s | -04° 55' 19" | Virgo | -4.2 | 03:14 | 14:36 |
| 30 NOV | 13h 36m 42s | -07° 45' 32" | Virgo | -4.2 | 03:32 | 14:24 |
| 2 NOV | 14h 48m 38s | -16° 11' 06" | Libra | +1.5 | 07:22 | 16:40 |
| 9 NOV | 15h 08m 07s | -17° 37' 56" | Libra | +1.5 | 07:23 | 16:23 |
| 16 NOV | 15h 28m 03s | -18° 58' 09" | Libra | +1.4 | 07:23 | 16:07 |
| 23 NOV | 15h 48m 28s | -20° 10' 49" | Libra | +1.4 | 07:24 | 15:52 |
| 30 NOV | 16h 09m 21s | -21° 15' 03" | Scorpius | +1.4 | 07:24 | 15:39 |
| 2 NOV | 02h 33m 00s | +13° 32' 08" | Aries | -2.9 | 16:32 | 07:02 |
| 9 NOV | 02h 29m 17s | +13° 14' 59" | Aries | -2.9 | 16:02 | 06:29 |
| 16 NOV | 02h 25m 43s | +12° 58' 36" | Aries | -2.9 | 15:32 | 05:57 |
| 23 NOV | 02h 22m 26s | +12° 43' 41" | Aries | -2.9 | 15:03 | 05:24 |
| 30 NOV | 02h 19m 32s | +12° 30' 49" | Aries | -2.9 | 14:34 | 04:53 |
| 2 NOV | 22h 11m 34s | -13° 01' 50" | Aquarius | +0.7 | 14:30 | 00:21 |
| 9 NOV | 22h 11m 39s | -13° 00' 32" | Aquarius | +0.8 | 14:02 | 23:54 |
| 16 NOV | 22h 12m 03s | -12° 57' 23" | Aquarius | +0.8 | 13:35 | 23:27 |
| 23 NOV | 22h 12m 47s | -12° 52' 27" | Aquarius | +0.8 | 13:08 | 23:01 |
| 30 NOV | 22h 13m 50s | -12° 45' 47" | Aquarius | +0.9 | 12:41 | 22:35 |

# THIS MONTH'S PLANETS

**Venus continues to dazzle in the dawn sky as a bright spark of light**

## PLANET OF THE MONTH




### VENUS

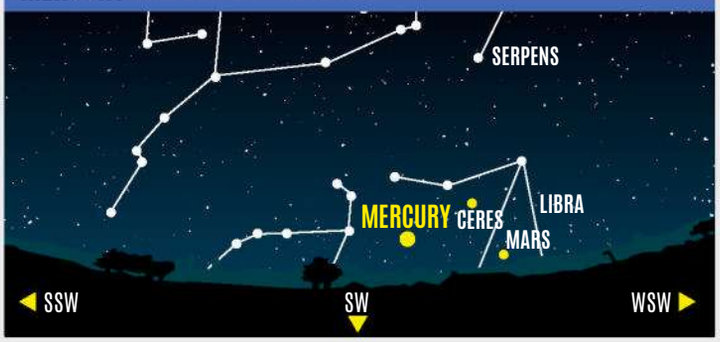
**Constellation:** Virgo
**Magnitude:** -4.5
**AM/PM:** AM

Venus is the second-closest planet to the Sun, and it alternates between being a morning and an evening star. All through this month it will be a dazzling morning star, rising well before the Sun and outshining everything else in the sky apart from the Moon. At the very start of the month it will be shining in the constellation of Leo, and far brighter than any of its stars, but by 4 November it will have drifted over into Virgo. Venus will rise more than four hours before the Sun, and will still be visible as a silvery-blue spark as the eastern sky begins to brighten with the approach of dawn. Between rising and slowly fading away, Venus will look like a beautiful lantern in the sky, drawing your eyes away from everything else.

But why is Venus so bright in our sky? It helps that Venus is very close to us – in cosmic terms, at least – and it's the same size as Earth, so you would expect it to be bright. But the main reason Venus is so bright is that it's covered in a dense, thick atmosphere of choking carbon dioxide gas. Even on the cloudiest of days, looking down from the International Space Station astronauts can see the surface of Earth through gaps in the clouds. However, if any astronauts ever visit Venus all they will see through their windows will be a featureless expanse of yellow-grey, because Venus' atmosphere is completely impenetrable and opaque, with no gaps in the clouds to allow glimpses of its rocky, Sun-scorched surface. This thick atmosphere acts like a mirror, reflecting the Sun's light back into space and making Venus a dazzling sight in our sky.

Between 8 and 10 November, the waning Moon will approach and then pass the planet, making a spectacular sight in the southeast before dawn. By the end of the month Venus will be rising more than five hours before the Sun, and will be a stunning sight before dawn wherever you see it from. Even if you live in a busy town or city it will easily shine through the light pollution there. If you're lucky enough to live or be visiting somewhere blessed with a dark sky, Venus will be so bright in your predawn sky that it will be a spectacular sight, so bright that it will easily be reflected in the waters of any river or lake you view it over and even bright enough to cast a faint shadow behind you as you face it.

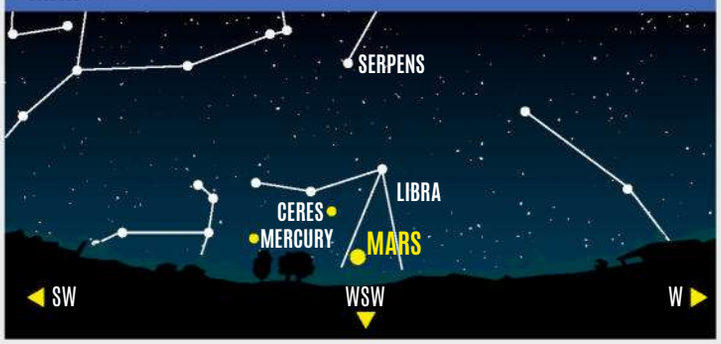
## MERCURY 16:12 GMT on 8 November




**Constellation:** Leo/Libra **Magnitude:** -0.5 **AM/PM:** PM

Being the closest planet to the Sun in the Solar System always makes Mercury hard to see in the sky, because it never strays far from its glare, and at the start of November Mercury will be so close to the Sun in the sky that it will be lost in its fiery glare. Unfortunately, this will remain the case until the very end of the month.

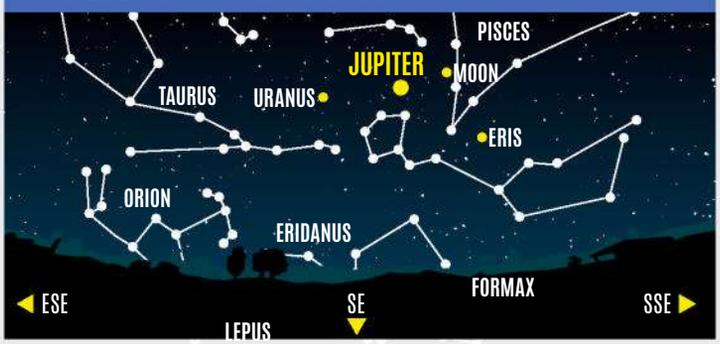
## MARS 16:15 GMT on 9 November




**Constellation:** Libra **Magnitude:** +1.7 **AM/PM:** PM

At the start of November Mars will be too close to the Sun to be visible. In fact, it will be less than five degrees from it – just a few Moon widths – so you'll have no chance of seeing it in the evening twilight. Mars will draw closer to the Sun every day until it passes behind it mid-month and is completely lost from our sight.

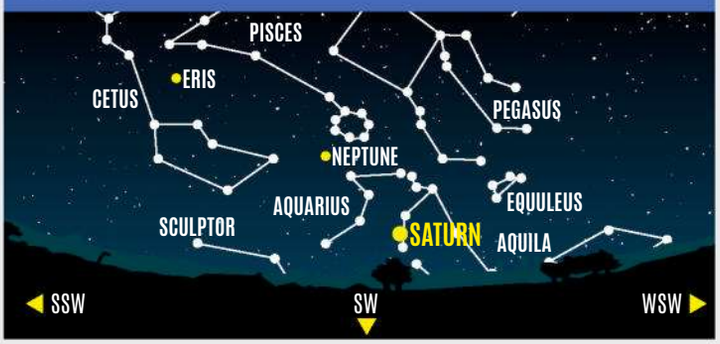
## JUPITER 20:30 GMT on 24 November




**Constellation:** Aries **Magnitude:** -2.8 **AM/PM:** PM

This month Jupiter will be an evening star shining brightly in the constellation of Aries, rising in the east as the Sun sets in the west. A short distance to Jupiter's left, or east, you'll see the misty haze of the Pleiades star cluster, and halfway between the two the distant ice giant world Uranus.

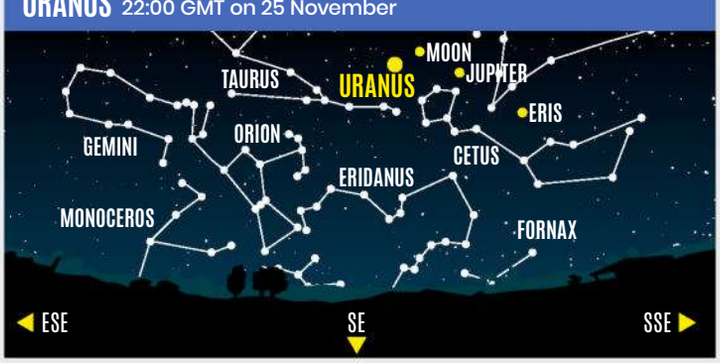
## SATURN 21:30 GMT on 20 November




**Constellation:** Aquarius **Magnitude:** +0.5 **AM/PM:** PM

At the start of November Saturn will already be low in the southeast as the Sun sets and will be visible all through the evening, tracing out a low arc across the southern sky. By month's end Saturn will be rising in daylight and setting around 22:30, so if you want to see it you will need to be quick, even with the dark nights.

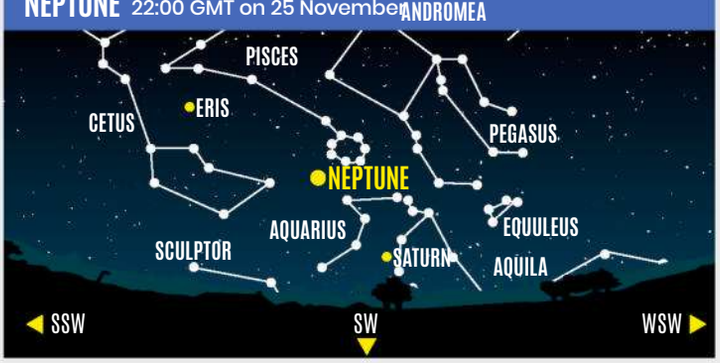
## URANUS 22:00 GMT on 25 November




**Constellation:** Aries **Magnitude:** +5.6 **AM/PM:** PM

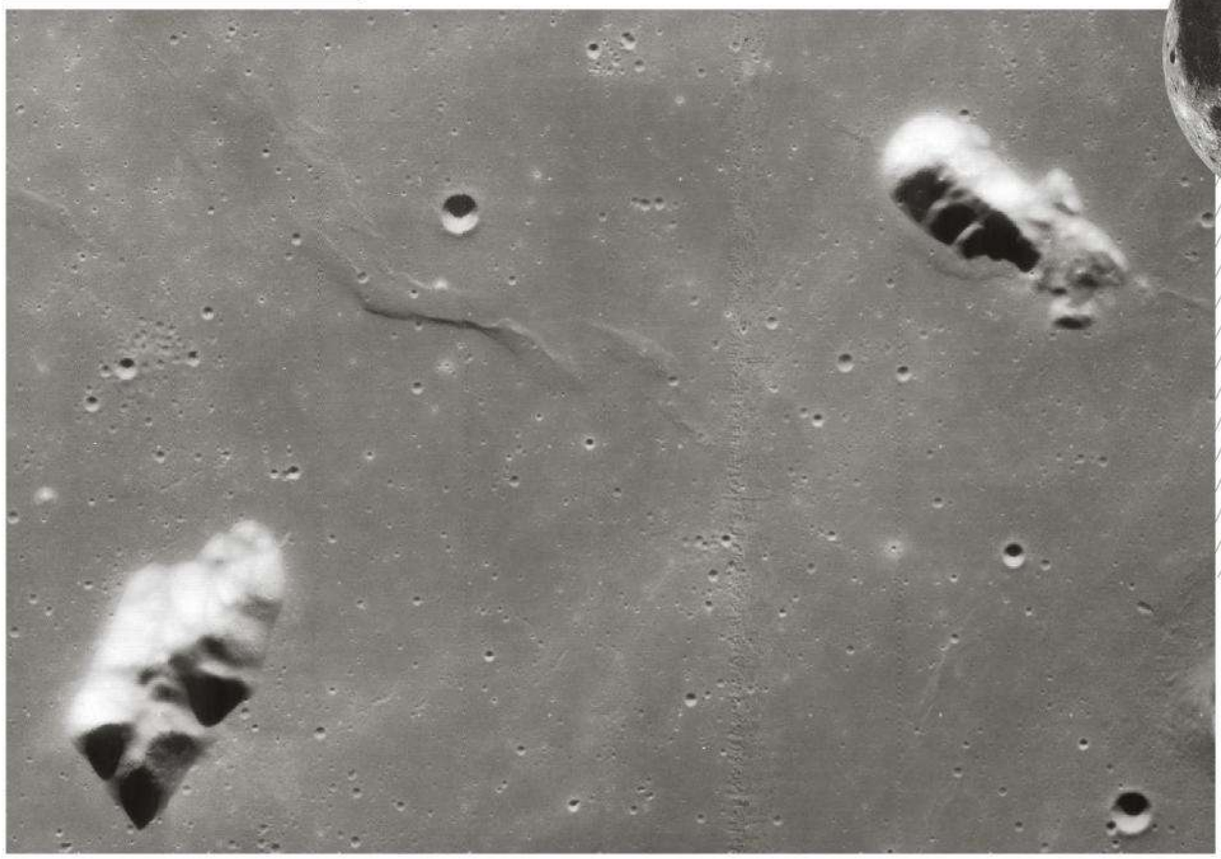
With a magnitude of +5.6 it will technically be visible to the naked eye, but it will be in part of the sky where there are many stars of that same magnitude or brighter. If you have a binocular, try sweeping slowly between the Pleiades star cluster and bright Jupiter, as Uranus will be shining halfway between them.

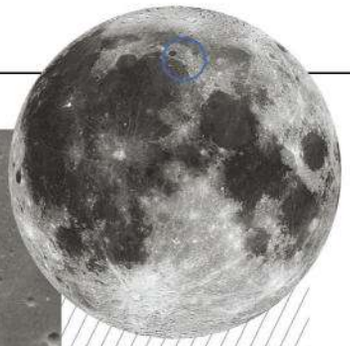
## NEPTUNE 22:00 GMT on 25 November




**Constellation:** Pisces **Magnitude:** +7.8 **AM/PM:** PM

Neptune is much too faint to be seen with the naked eye, even on the darkest clear night away from light pollution. If you have binoculars or a telescope you'll be able to spot it in the evening sky, not far from much brighter Saturn, during November as a magnitude +7.8 blue-green star in the constellation of Pisces.





**TOP TIP!**

The best time to see the mountains near Plato is when they're near the terminator. This month that will be on 6 and 21 November.

## MOON TOUR

# MONS PICO AND PLATO'S MOUNTAINS

### These lunar peaks are worth exploring with a telescope

If you have binoculars you can see a surprising amount of detail on the Moon. They will show you its largest craters – huge holes blown out of its surface by the impact of asteroids millions or even billions of years ago. They will also show you its highest mountain ranges, some of which rival Earth's most beautiful. But the most striking sights in binoculars are the Moon's seas, or 'mare', which are not bodies of water, but huge, flat plains of ancient lava which flowed out of the Moon like the yolk of an egg and spread across its surface before freezing in the aftermath of enormous asteroid impacts which set the Moon ringing like a cosmic bell.

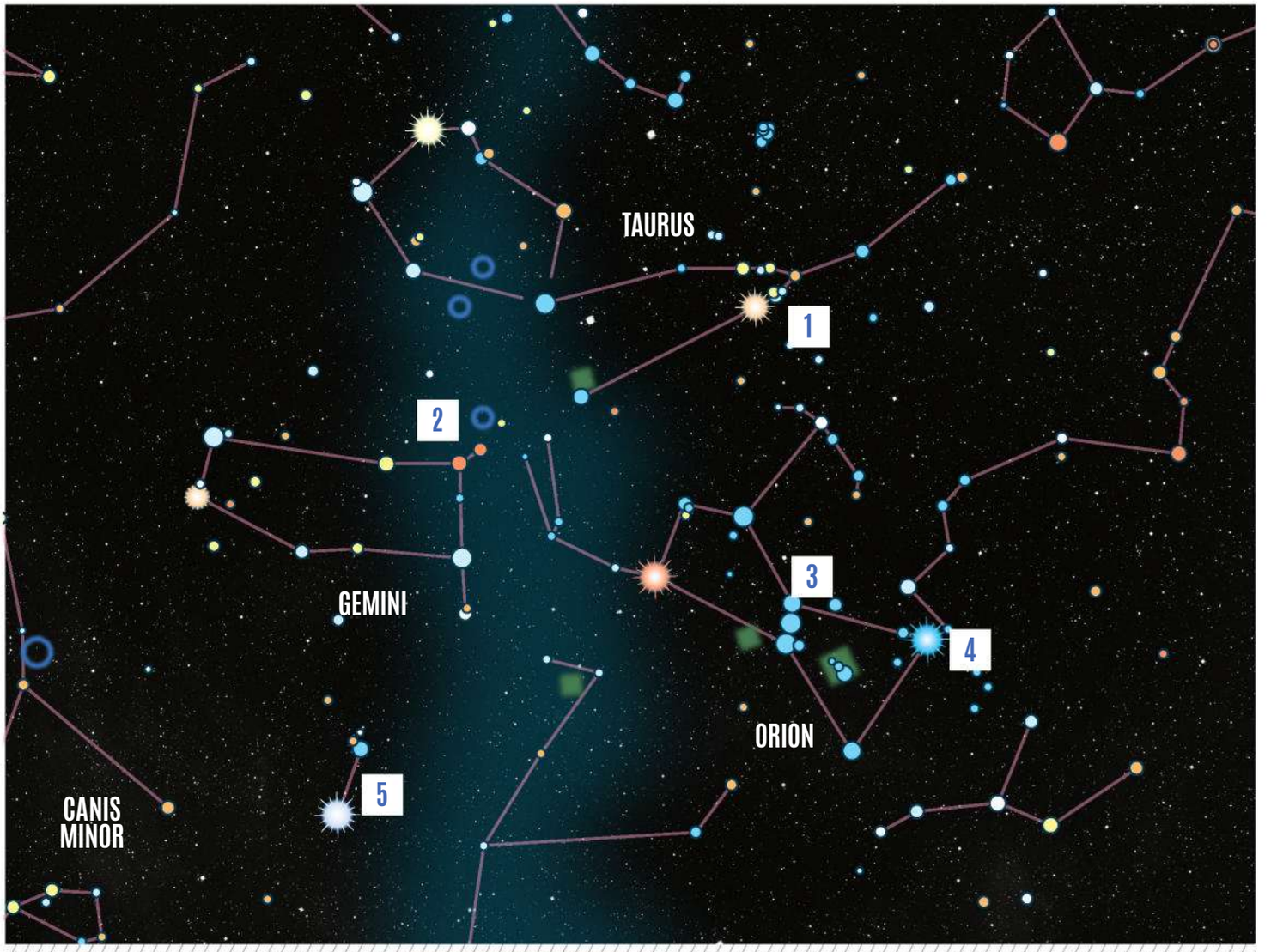
One of the largest seas is Mare Imbrium, which forms the bloated right eye of 'the man in the Moon' when the Moon is full. It's top and centre on the disc. Looking at it through binoculars, you'll see a small, dark circle or oval at the top of Mare Imbrium. This is a walled plain called 'Plato', and it's one of the most famous features on the Moon. But if you have a telescope there is something worth looking at just to the south of Plato – something you'll want to look at with the highest magnification your telescope can manage.

When Plato is close to the terminator this month, focus your telescope on it, put in a high-power eyepiece and look just to its south. There you'll see what looks like a chain of some small rugged 'islands' out in the dark sea, close to the northern shore of Mare Imbrium. These nubs and stubs of rock are actually mountains, sticking up out of the lava plain of Mare Imbrium like pieces of bone or fossils exposed by the digging and brushing of patient archaeologists. You'll see them running from west to east in your eyepiece in a ragged chain. The more westerly ones are Montes Teneriffe, which were named after the island of Tenerife in the Canaries.

Look a little further east and just to the south and you'll see a mountain sticking up out of the lava plain all on its own. This is Mons Pico, named after the volcano in the centre of Pico Island in the Azores. That volcano rises up 2.3 kilometres (1.4 miles) from the ocean, and the peak of its lunar namesake is 2.4 kilometres (1.5 miles) above Mare Imbrium, making it just a little higher. Mons Pico is by no means the tallest or most impressive peak on the Moon, but it is one of the most striking. When the terminator is either approaching it or has just swept over it, Mons Pico can cast a long, very dark and very obvious shadow across Mare Imbrium that really makes it stand out. For this reason it's a firm favourite of many lunar observers.

So when can you see this peak this month? At the start of our observing period it's bathed in full sunlight because the Moon will be just past full, so it will just look like a flat, white blob in your telescope. Look again around 6 November and by then Mons Pico will be casting a shadow as the Sun begins to set in its sky. By 7 November Mons Pico will be on the terminator and will vanish from view, not to return until around 21 November, when the Sun will rise in its sky again and it will stand out starkly on the Moon once more, casting a long, ink-black shadow across the lava plain it stands in.

© NASA




# NAKED EYE AND BINOCULAR TARGETS

## The night sky is rich in pretty star clusters and bright, colourful stars

### 1 Hyades cluster

The Hyades is a distinctive V-shaped star cluster representing the shoulder of Taurus, the Bull. It's only 142 light years away, contains between 300 and 400 stars and is easy to see with the naked eye. Dazzling bright-red Aldebaran is not a cluster member, as it lies between us and the cluster.

### 2 Messier 35

Messier 35 is an open star cluster 3,000 light years away and more than 24 light years wide. It contains perhaps 3,200 stars, and although it can be seen as a tiny smudge to the naked eye, it is a striking sight in binoculars and most small telescopes.

### 3 Orion's Belt

One of the most famous patterns of stars in the entire sky, Orion's Belt is made up of three blue-white stars of approximately the same brightness. Astronomers use it as a pointer to guide them to other sky sights. It gestures down to Sirius, the brightest star in the sky, and up to the Hyades star cluster.

### 4 Rigel (Beta Orionis)

Shining at magnitude +0.18 in Orion's bottom-right corner, Rigel is the brightest star in Orion and the seventh-brightest in the sky. About 860 light years from Earth, it's a blue-white supergiant star 17 times more massive than our Sun and an amazing 40,000 times more luminous.

### 5 Procyon (Alpha Canis Minoris)

Magnitude +0.3 Procyon is the eighth-brightest star in the sky. Its name means 'before the dog' in Greek, and it does indeed rise into the sky before Sirius, the much brighter 'Dog Star'. It is 14 light years away and is the 14th-closest star to our Sun.

2 Witch Head Nebula (IC 2118)

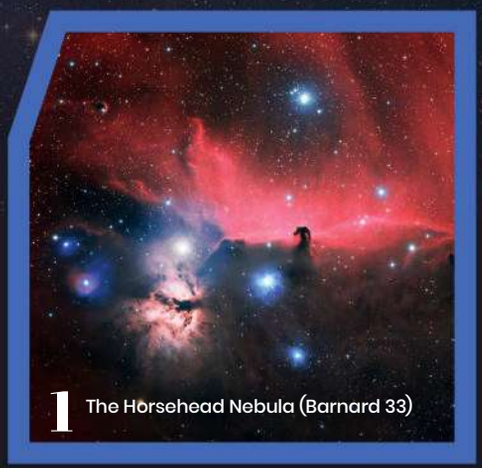
DEEP SKY CHALLENGE

# TOUR BEYOND THE ORION NEBULA

## Track down some of winter's lesser known wonders on the next clear and chilly night

Just as it's easy for us to return to the same 'celestial celebrities' night after night during the summer months – the Ring Nebula, Messier 13 and Messier 51 all repeatedly drawing the eye away from other things – the deep-sky observer's winter comforts are the bright swirling clouds of the stunning Orion Nebula and the glittering spectacle of the Pleiades.

But there are many other objects in the winter sky just as deserving of our attention. Given that November nights are often beautifully clear and cold, this is a good time to wrap up warm, head out and track down some of the objects that are often overlooked in favour of their brighter, brasher neighbours. While most amateur astronomers have heard of the Horsehead Nebula, very few have ever actually seen it. Although photographs suggest it's a very dramatic-looking object – a bold knight chess piece silhouetted against a cherry-red curtain of light – in all but the largest telescopes it's little more than a dark notch in a slightly lighter area. Likewise, the Rosette Nebula can be seen on every wide-field photo taken of Orion, looking like an orange flower to the left of Betelgeuse, but its low surface brightness and wide area mean it's little more than a puff of smoke with a star-spangled centre through most telescopes.



1 The Horsehead Nebula (Barnard 33)

## 1 THE HORSEHEAD NEBULA (BARNARD 33)

This dark nebula looks strikingly similar to a horse's head in long exposures, but you'll need a large telescope, a very dark sky, perfect seeing and maybe even a filter if you're going to see it.

## 2 THE WITCH HEAD NEBULA (IC 2118)

Illuminated by the icy-blue glare of nearby giant star Rigel, this tenth-magnitude cloud of gas looks like the face of a crooked-nosed witch through large-aperture telescopes.

## 3 THOR'S HELMET (NGC 2359)

Finding this 11th-magnitude nebula is a huge challenge. Observing under a dark sky, a large telescope fitted with a nebula filter will show hints of filaments and mottling within it.

## 4 THE SEAGULL NEBULA (IC 2177)

If you use averted vision looking at this tenth-magnitude nebula through a large telescope's widest field eyepiece, you might see it has a bright 'head' and faint, outstretched 'wings'.

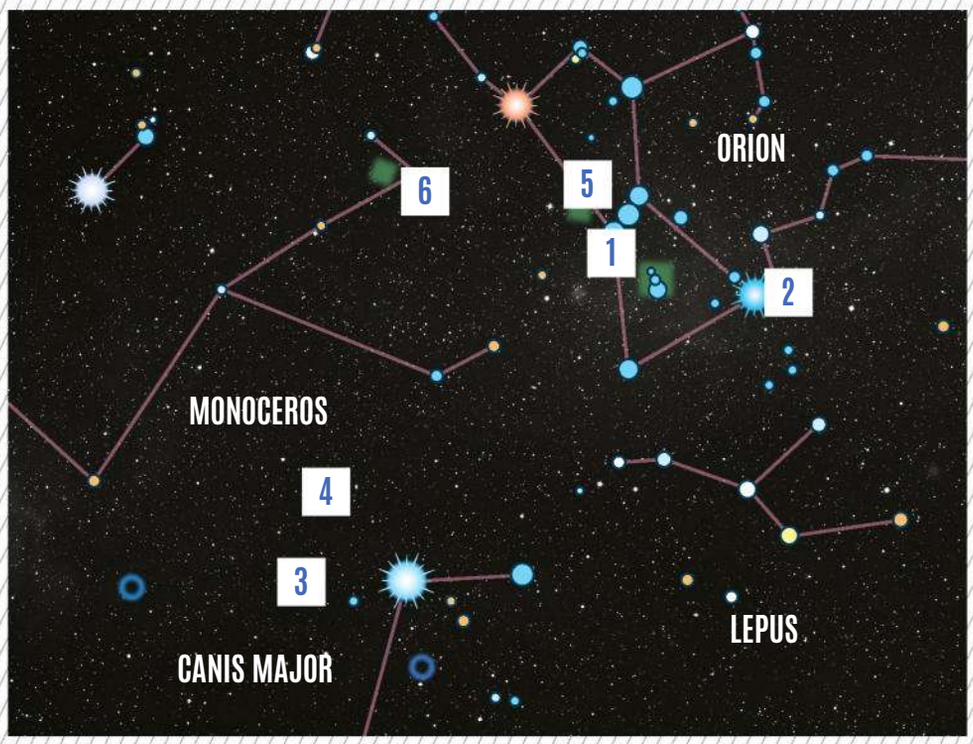
## 5 MESSIER 78

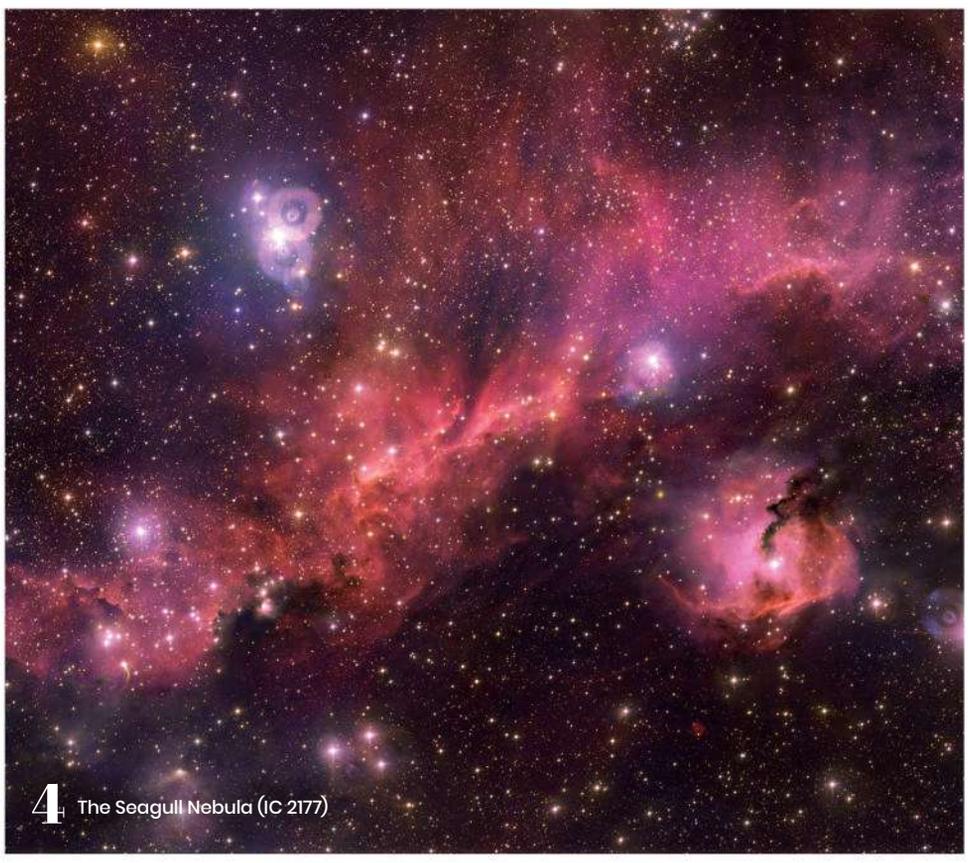
Although a small telescope will easily show this nebula's bright centre, larger instruments and high magnifications are needed to see subtle detail at its edges.

## 6 THE ROSETTE NEBULA (NGC 2237)

The Rosette Nebula is bright and colourful in photos, but visually it appears as a vague, grey-white smudge through large-aperture telescopes on Moon-free nights.

**"While most amateur astronomers have heard of the Horsehead Nebula, very few have ever actually seen it"**



4 The Seagull Nebula (IC 2177)

© NASA; ESO; Source: Wikipedia Commons - Stephanh

# NORTHERN HEMISPHERE

## Astronomers will need to wrap up warm to make the most of the winter sky

Astronomers can now make the most of darker evenings. But having longer hours of darkness doesn't merely give sky-watchers more time to become reacquainted with old favourites – it also offers the chance to seek out previously unexplored targets. If you're a fan of splitting double stars with a telescope, head over to the constellation of Aries (the Ram), which can be found surrounded by Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Mesarthim are splendid targets to resolve for astronomers with medium to large instruments.

### Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

### Magnitudes

- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

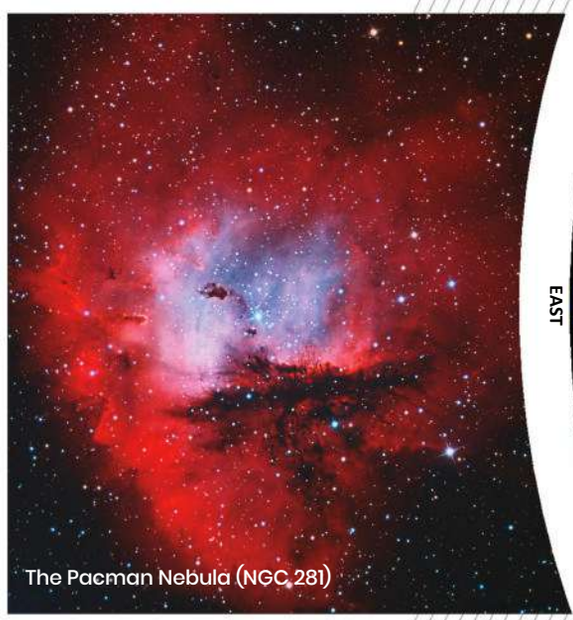
### Spectral types

- O-B
- A
- F
- G
- K
- M

### Deep-sky objects

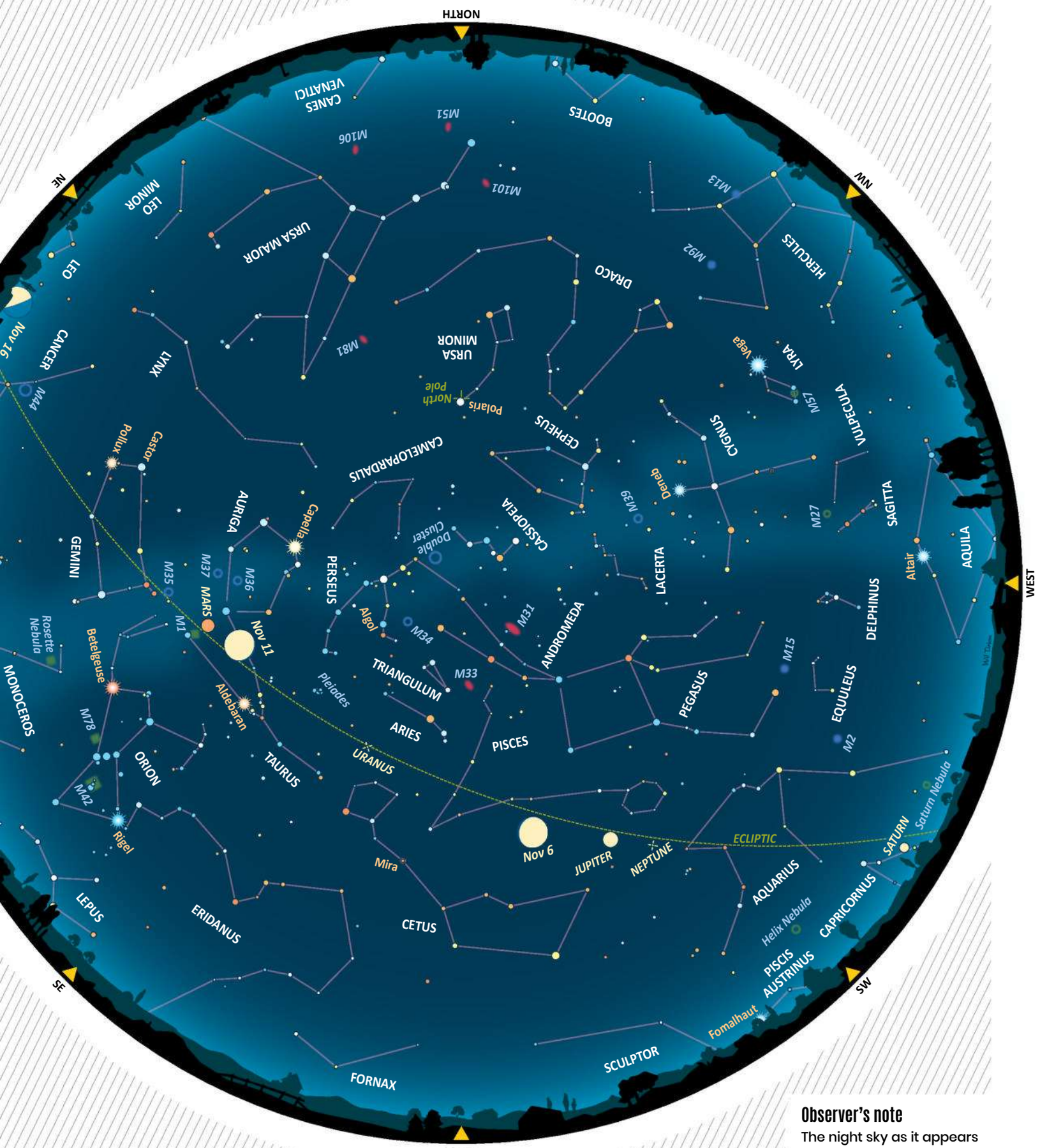
- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

The Rosette Nebula (Caldwell 49)



The Pacman Nebula (NGC 281)

Triangulum Galaxy (Messier 33)




**Observer's note**

The night sky as it appears on 17 November 2023 at approximately 22:00 (GMT)

© Getty

REVIEW

# NIKON ACULON T02 821 BINOCULAR

**Stylish, small and lightweight, the Nikon Aculon T02 8x21 offers limited yet pleasing views of planets, the Moon and star fields**

Reviewed by Gemma Lavender

## DETAILS

**Cost:** £59.99 / $69.95

**From:** Nikon

**Magnification:** 8x

**Objective lens diameter:** 21 millimetres

**Angular field of view:** 6.3 degrees

**Eye relief:** 10.3 millimetres

**Weight:** 195 grams

**Additional kit:** Carrying case and eyecup lens caps

If you're an observer who's always on the go and you're looking for a piece of kit that fits comfortably in your pocket, then the Nikon Aculon T02 8x21 is a great lightweight option, weighing in at a mere 195 grams. The Nikon Aculon T02 8x21 truly offers the ultimate portable experience, with dimensions that make it similar in size to a smartphone. What's more, if you're looking for a binocular that's stylishly unique, then the Nikon Aculon T02 8x21 wins hands down in our opinion, as this model comes in a selection of colours: red, blue and white. The Nikon Aculon T02 8x21 comes equipped with a carrying case and eyepiece covers, but it's worth noting that the case wasn't supplied with the test unit we received from Nikon.

Optically, and with an aperture of just 21 millimetres, this binocular might not be the first choice for keen observers of the night sky due to the limited light-gathering prowess, but for those who like to dabble in gazing upon magnified views of the Moon and detailed sights of wildlife, then this fogproof piece of kit suits a variety of budgets. Popping the binocular out of the box, we admired the smooth, lightweight build, which was a true delight to hold. A sleek, ergonomic design offers a comfortable grip, and as the rain battered the windows outside, curtailing our observations for

The Nikon Aculon T02 comes in red, blue and white colour variations

## BEST FOR...

- MEDIUM BUDGETS
- YOUNG SKYWATCHERS
- CASUAL NIGHT SKY OBSERVATIONS
- BRIGHT PLANETS
- THE MOON
- STAR FIELDS

Though the binocular doesn't completely fold, it's still very compact

The small size makes it useful for young observers

## "A sleek, ergonomic design offers a comfortable grip"

the night, we took to sweeping the binocular around the room. Weighing in at a very light and compact 195 grams, our arms didn't tire as we peered out of the window at a lamp post, dazzling with an orange light that came out crisp and clear in the field of view.

The binocular boasts a 110-metre field of view at 1,000 metres, and as we scanned the rooftops of houses in the twilight we were pleased to see crisp tile edges in the low light. Good eye relief binoculars for spectacle wearers usually sit between 14 and 16 millimetres, so the Aculon T02 8x21 falls short at 10.3 millimetres. While some spectacle wearers may not have too much trouble, we recommend taking them off while using this binocular for comfortable views through the 'turn-and-slide' rubber eyecups. Despite this minor niggle, our overall experience was nothing short of pleasant. As we waited for the sky to clear, we explored the binocular's design. It's not possible to fully fold the Aculon T02 8x21 like similar compact binoculars we've used, yet with dimensions of 8.7 by 10.4 by 3.4 centimetres, we could slot them into our coat pocket with plenty of room to spare. While the lens covers are snug, they could be pulled off easily, ensuring that you can quickly observe without fumbling to get the covers off when the occasion arrives.

The Aculon T02 8x21 isn't marketed as being rugged, but we feel that it's robust enough to withstand a great deal of travelling, observations and clumsy use, making it ideal for parents looking to buy their children a binocular that can take a few knocks and bumps. The binocular is nitrogen-filled, leaving us wondering how the Aculon T02 8x21 would fare later on during our observations, but from the dryness of the kitchen, we held the Aculon T02 8x21 out under slight drizzle to see how the build held up under damp conditions. It's important to note that the Aculon T02 8x21 will not be able to survive under massive downpours. Nikon has warned that the binocular is not waterproof in the supplied manual.

Bringing the binocular back inside and gently wiping away water spray from the casing, objective lenses and eyecups using a microfibre cloth, we peered through the Nikon Aculon T02 8x21 at a well-lit fish tank to illuminate the optics. It's worth noting here that as we fiddled with the focuser, its operation was very smooth. The casing had withstood our test and no water had leaked into the housing, leaving us satisfied that the binocular can endure a touch of moisture.

The long summer days and intermittent bouts of rain meant that we had to not only wait for the Sun to set well into the evening, but also wait for several nights for the wall-to-wall cloud to clear after our first introduction to the Aculon T02 8x21. Given the small objective lens, and therefore suspecting it not to be able to handle low-light conditions, our expectations were

low for astronomical viewing through the optical system.

The night finally arrived in July, and as we stepped out under the Summer Triangle in the east, which is comprised of the stars Vega, Deneb and Altair in Lyra (the Harp), Cygnus (the Swan) and Aquila (the Eagle) respectively, we were excited to see what the Aculon T02 8x21's optical system would pick up. With our experience of binoculars with small objective lenses and magnification, we knew to stick to brighter, easier access Solar System and deep-sky targets with magnitudes of at least +4.0. The most obvious choice during our observations was the first quarter Moon, which was at a reasonable altitude above the treeline at an illumination of about 47 per cent. Bringing our natural satellite into our sights, with our pin-sharp view remaining steadfast thanks to an impressively accurate focuser, we were delighted with the level of lunar detail that met our eyes. While the Moon appeared small, we could still appreciate Oceanus Procellarum before sweeping our pupils along the terminator to the crater Kepler.

The brightness of the Moon allowed us to truly study the Aculon T02 8x21's optical system. While views were beautifully pin-sharp thanks to the multi-coated optics, we did detect a touch of chromatic aberration, also known as colour-fringing, along the lunar limb. While noticeable as a purple-blue edging, our views were unspoilt. We spent some time admiring the Moon before sliding the binocular in our trouser pocket and heading back inside to make a cup of tea. Stepping back outside about 15 minutes later, with the intention of drinking in star fields through the optics, we were pleased to see that the nitrogen purging had had an effect, with no great fogging disrupting our observing session.

In the height of summer, the Milky Way is a prime target, and laying back in a recliner we lazily swept its dusty path through the constellations, including Sagittarius (the Archer), Scorpius (the Scorpion) and Cygnus (the Swan). We were treated to sections of sky that seemed to become even more populated with stars as the night wore on – a beautiful, high-clarity sight that is sure to entrance the entire family. This was a highlight through the Aculon T02 8x21. Jupiter and Saturn kept us company into the early hours of the morning, making them ideal targets to observe at magnitudes -2.7 and +0.5 respectively. As expected, our views weren't massively magnified over the unaided eye, but we did enjoy the stunning white disc of Jupiter and a gorgeous, unblinking yellow-white Saturn through the optical system.

As has been made clear throughout our test, the Nikon Aculon T02 8x21 doesn't have a great deal of light-gathering prowess, meaning that it is particularly challenging to observe some of the fainter deep-sky gems of the night sky of less than +6.0 magnitude – namely nebulae, which team the summer sky, and galaxies. Despite this expected drawback, however, superb colour fidelity is offered with this binocular, provided the skywatcher is mindful of the optical system's limits. It's important to note that the Nikon Aculon T02 8x21 doesn't boast the BaK4 prisms that are most commonly found in skywatching binoculars.

The eyecups are twistable and are a delight to use, since there is no sticking or exertion required in pulling them out to put to use. Their operation is smooth, and they're just as easy to fold in when packing the binocular away. The functionality of the focusing wheel is also pleasing. The grooves in its design, combined with the ability to make minute movements, enables targets to be brought into focus with ease for sharper, clearer views. While the Nikon Aculon T02 8x21 won't break the bank, it's possible to pick up binoculars with a higher magnification and larger objectives for a similar price, or by investing a few pounds or dollars more. We advise choosing a model that features BaK4 prisms and a waterproof design.

Nikon hasn't skimped on quality. Despite the reasonable price, the Nikon Aculon T02 8x21 exudes an excellent build and decent optics, allowing for a variety of high-performance, high-clarity observing activities on the go. If you're not too invested in observing the night sky but want somewhat magnified views wherever you go, whether that's of a bright night-sky object, a bird in a tree or a lion on a safari, then we wholeheartedly recommend this binocular – provided you stay out of torrential rain.

The binocular is still compact when unfolded and has an accurate focuser

## FOR

- Excellent pin-sharp images
- Lightweight for long observing sessions
- Good field of view
- Robust design
- Fogproof

## AGAINST

- Not suitable for detailed astronomy work
- Poor eye relief for spectacle wearers
- Colour fringing when observing bright objects

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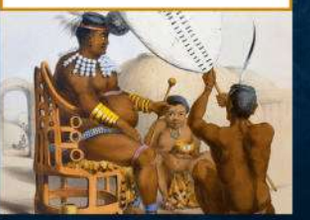
| | | | |  |

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# IN THE SHOPS: BEST SMARTPHONES FOR ASTROPHOTOGRAPHY

## Apple iPhone 13 Pro Max

**Cost:** £849 / $999
**From:** Apple

1 Unsurprisingly, Apple is a big hitter in this guide, and its 6.7-inch flagship smartphone is top of the range. The bigger sensor on this camera phone means it produces brighter photos even in low light and at night. It also has a high-quality Night Mode, meaning decent images of the night sky are possible, and if you're ever in the Arctic Circle, that means good photos of the aurora borealis are also possible. That Night Mode automatically kicks in when it's dark, just like the built-in high dynamic range (HDR) mode for all your shots. Simplicity is complemented by advanced hardware, with the latter boasting a 3x optical and 15x digital zoom.

## Samsung Galaxy S21 Ultra

**Cost:** £629 / $679
**From:** Samsung

2 A large part of why this is one of the leading Android camera phones is its incredible 108-megapixel image sensor. Although technically you can take ultra-high resolution images, that massive megapixel capability is there to improve pictures taken in low light. The 6.8-inch Galaxy S21 Ultra takes nine separate 12-megapixel images and then loses the 'noisy' pixels to create a cleaner and more detailed photo. You can also use that sensor to take pure 108-megapixel images, but why would you need to do that? Especially since you can't expand its maximum built-in storage of 512GB. The 10x optical and whopping 100x digital zooms are more interesting for photographers, which can be helpful when you put the Galaxy S21 Ultra on a tripod.

## Huawei P40 Pro+

**Cost:** £459 / $549
**From:** Huawei

3 The P40 Pro+ brings 10x optical zoom via an actual zoom lens – a first when the phone launched in 2020 – which means more detail and editing options than any resolution-killing digital zoom. However, there's a lot more to get excited about on this 6.58-inch smartphone, which brings no fewer than seven lenses, including a 3x optical telephoto ultrawide lens and a time-of-flight depth sensor. Its Night Mode boosts dynamic range and sharpness to produce clean, colourful images that most obviously reveal more detail in shadows. It also works well on the telephoto lens, though less well on the ultrawide lens. Unfortunately, Huawei smartphones now don't support Google Play apps and services, which may make them less desirable.

"Some of the changes do make this handset better for photography"

4

5

6

## Google Pixel 6 Pro

**Cost:** £405 / $349
**From:** Google

4 This is the best around for in-camera software and photo editing. Fire up the camera app and you'll find all the usual modes, such as portrait, panorama and a low-light mode called Night Sight, but there's also a new mode called Motion that's purely for taking creative long-exposure shots. The 6.7-inch Pixel 6 Pro also comes with advanced new features, including Real Tone and Magic Eraser for removing people and objects from photos after the fact. A 50-megapixle wide lens, a 12-megapixel ultrawide lens and a 48-megapixel telephoto lens with 4x optical zoom mean the hardware is pretty good. The Pixel 6 Pro is a standout choice, especially as you can choose some unusual colour choices and mix style with substance.

## Apple iPhone 13 Pro

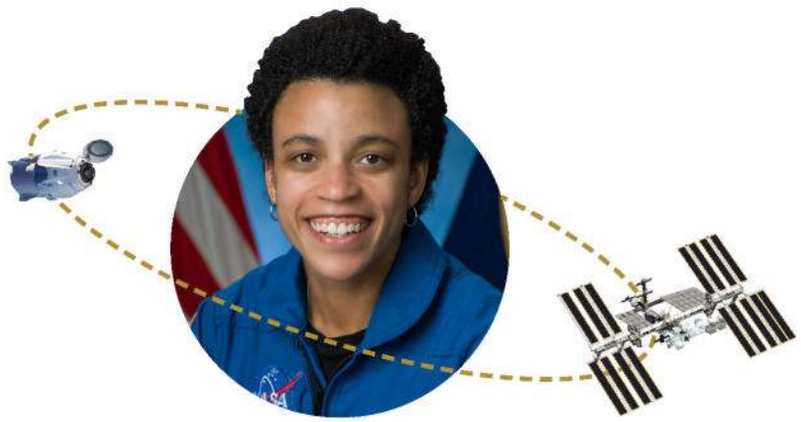
**Cost:** £679 / $679
**From:** Apple

5 Not much has changed design-wise since the iPhone 12 Pro, but some of the changes do make this handset better for photography. There are also some crucial differences between the iPhone 13 and the iPhone 13 Pro. Although both measure 6.1 inches, the latter has a brighter screen, extra battery power and a much better photography suite than the mainstream handset. Its rear camera array includes an ultrawide and a wide lens with larger apertures, a telephoto lens with 3x optical zoom and a LiDAR scanner for quicker autofocus and taking portraits in Night Mode. On the iPhone 13 Pro, it's also possible to take images in professional quality using Apple ProRAW and indulge in ProRes video recording up to 4K at 30 frames per second.

## OnePlus 9 Pro

**Cost:** £529 / $499
**From:** OnePlus

6 A 6.7-inch handset running Android 13, it sports a stunning AMOLED QHD+ display that beats most smartphones with its colour and black levels. Its camera array on the rear is busy, with four lenses and laser autofocus. So why is there a Hasselblad logo back there? The ultra-high-end medium-format camera photography company has co-developed the 9 Pro's camera array with OnePlus, with Natural Colour Calibration as its substance. Skin tones do look great through its cameras, though the photography highlight is its ultra-wide-angle lens that corrects for edge distortion. Meanwhile, its main camera records in 12-bit RAW, and it has the ability to record in 4K at 120 frames per second and even in 8K at 30 frames per second.



# JESSICA WATKINS

## Joining NASA in 2017, she's one of the Artemis astronauts who could fly to the Moon

Watkins was born on 14 May 1988 in Gaithersburg, Maryland. Her family moved to Lafayette, Colorado, where she attended Fairview High School. After high school, Watkins enrolled at Stanford University in California, where she earned a bachelor's degree in geological and environmental sciences. At Stanford, Watkins also played rugby, playing on national teams and even placing third at the 2009 Rugby World Cup Sevens with the USA Eagles. Watkins later earned a PhD in geology at the University of California, Los Angeles. She conducted undergraduate internships at NASA's Ames Research Center in California, studying analogue Mars soil to support the Phoenix Mars lander mission.

In 2017, Watkins was selected as part of NASA's new astronaut candidate class. Her training lasted about two years and consisted of scientific and technical instruction that included extensive coverage of the systems aboard the International Space Station, as well as information about spacewalks. This preparation also involved physiological training, practice flying T-38 supersonic jets, geology training, what NASA refers to as 'expeditionary skills' training and training in water and wilderness survival. This survival training has previously included activities like camping with an emphasis on survival as opposed to leisure. In 2019, Watkins completed another analogue mission as part of her astronaut training. During this mission, Watkins worked as an aquanaut crew member at the underwater Aquarius habitat off the coast of Florida as part of the NASA Extreme Environment Mission Operations (NEEMO) 23 mission.

Watkins flew to space for the first time on SpaceX's Crew-4 mission. She served as a mission specialist alongside fellow NASA astronaut and mission commander Kjell Lindgren, NASA astronaut and mission pilot Robert Hines and European Space Agency astronaut and mission specialist Samantha Cristoforetti. This mission sent the crew on a six-month stay aboard the space station, where they lived and worked conducting research while in the microgravity environment of the orbiting laboratory. With this mission, Watkins became the first Black woman to accomplish an extended mission in space. In December 2020, Watkins was announced as one of 18 NASA astronauts who would serve on the space agency's 'Artemis Team', a group of astronauts that would train and eventually fly Artemis missions to the Moon.

NASA's early Artemis Moon missions include Artemis I, an uncrewed flight around the Moon which launched in November 2022; Artemis II, a crewed flight around the Moon to launch in 2024, and Artemis III, the first crewed lunar landing of the Artemis program.

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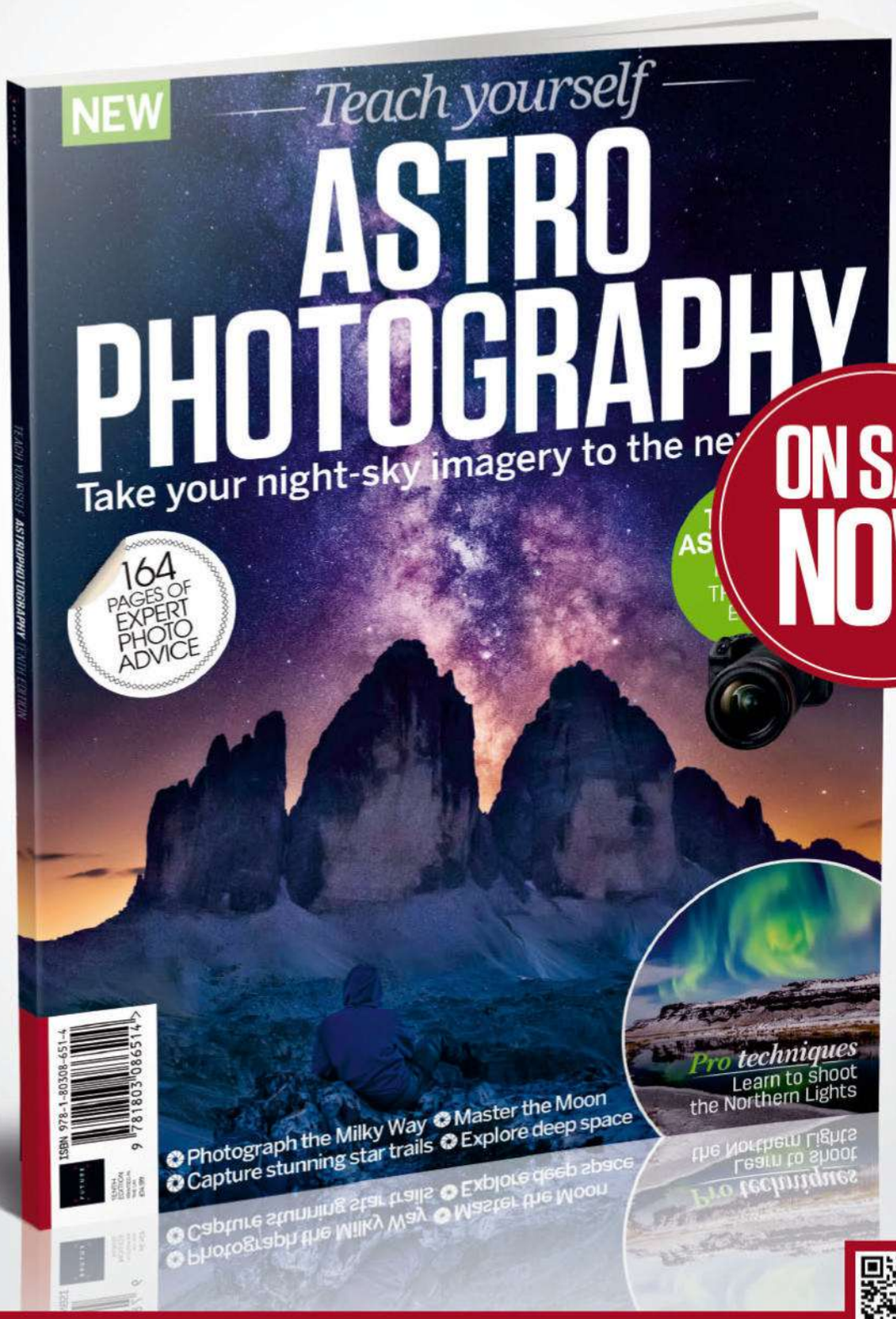


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